SMALL BUSINESS INNOVATION RESEARCH (SBIR)

Program Solicitation

CLOSING DATE: *June 13, 1994*

NATIONAL SCIENCE FOUNDATION
NSF 94-45

NATIONAL SBIR CONFERENCES

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The National Science Foundation's Small Business Innovation Research Program (NSF/SBIR) funds research in most fields of science and engineering as well as in science and engineering education. The awardee is wholly responsible for the conduct and reporting of each research project. The Foundation, therefore, does not assume responsibility for the research results or their interpretation.

The Foundation welcomes proposals on behalf of all qualified scientists, engineers, and science educators, and strongly encourages women, minorities, and persons with disabilities to compete fully in any of the research and research-related programs described in this document.

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For Additional Assistance Contact:

E-mail: *stis@nsf.gov* (Internet)

Phone: (703) 306-0214 (voice mail)

TDD: (703) 306-0090

NSF 94-4
(Replaces NSF 91-10)

NATIONAL SCIENCE FOUNDATION
SMALL BUSINESS INNOVATION RESEARCH PROGRAM
PROPOSAL CHECKLIST

Do not submit this checklist with your proposal.

DOES THE PROPOSAL MEET THE FOLLOWING REQUIREMENTS?

- Proposal **in totality** is 25 pages or less and conforms to page size and type requirements—**excluding from the page count only** NSF Form 1225 (Appendix A), the Certification Page, and the statements on Prior Phase II Awards. ☐
- COVER PAGE is complete—Appendix B. ☐
- CERTIFICATION PAGE is signed—Appendix B. ☐
- Project duration does not exceed 6 months. ☐
- Proposal is being submitted under one topic only. ☐
- PROJECT SUMMARY is complete—Appendix C. ☐
- Principal Investigator is primarily employed by this firm—if not, required documentation is included. ☐
- Review special instructions for Principal Investigators with academic affiliations and for Principal Investigators who have or are seeking research support through an academic institution—if applicable. ☐
- Consultant and/or subcontractor documentation is complete. ☐
- Statement of current and pending support is included. ☐
- A minimum of two-thirds of the research effort will be performed by the proposing firm. ☐
- That portion of the research effort performed by the firm will be performed in a facility under control of the firm—if not owned or rented, required documentation is included. ☐
- Proposal describes commercial potential. ☐
- PROPOSAL BUDGET is on NSF 1030 (Appendix D) and is for $65,000 or less. ☐
- Proposal budget excludes foreign travel and equipment purchase. ☐
- An original and 9 copies of the proposal are submitted. ☐
- Deadline for receipt at the National Science Foundation is 5:00 pm EDT, June 13, 1994. ☐
- Proposer has read **all** instructions in this 1994 SOLICITATION and has reviewed the description of the topic to which application is being submitted. ☐

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This program solicitation is issued pursuant to the authority of the National Science Foundation Act of 1950, as amended (42 U.S.C. 1861 et seq.) for the purpose of supporting scientific research or related activities and 15 U.S.C. 638 (PL 97-219, 96 STAT. 217, "Small Business Innovation Development Act of 1982," as amended), and is not subject to the Federal Acquisition Regulations, except for Phase II where the Cost Principles cited in 48 CFR, Subpart 31.2 will apply.

National Science Foundation programs described in this publication fall under the following categories in the latest Catalog of federal Domestic Assistance issued by the Office of Management of Budget and the General Services Administration:

47.041 - Engineering
47.049 - Mathematical and Physical Sciences
47.050 - Geosciences
47.070 - Computer and Information Science and Engineering
47.073 - Office of Science and Technology Infrastructure
47.074 - Biological Sciences
47.075 - Social, Behavioral, and Economic Sciences
47.076 - Education and Human Resources

A recorded message which gives the status of the SBIR solicitation with regard to NSF's proposal processing can be reached by calling, toll-free, 1-800-999-7973.

Status information on individual proposals will not be available.

WARNING: Proposals not meeting the National Science Foundation proposal content requirements which are listed and explained in the Solicitation will be returned to the submitting institutions as "inappropriate."

Read this 1994 SBIR Program Solicitation carefully before preparing your proposal because NSF SBIR proposal requirements may differ from those of other agencies and from NSF SBIR solicitations from other years.

NATIONAL SCIENCE FOUNDATION

PROGRAM SOLICITATION FOR SMALL BUSINESS INNOVATION RESEARCH (SBIR)

The National Science Foundation (NSF), an independent agency of the Federal Government, invites small business firms to submit research proposals under this Program Solicitation for Small Business Innovation Research (SBIR). NSF will support high quality research proposals on important scientific, engineering, or science/engineering education problems and opportunities that could lead to significant commercial and public benefit if the research is successful.

1. PROGRAM DESCRIPTION

1.1. The Federal SBIR Program

The SBIR Program is a three-phase process. Eligible small businesses are invited to propose innovative ideas that meet the specific research and R&D needs of the Federal Government. SBIR operates under the Public Law 97-219 as amended; the Small Business Innovation Research Program Reauthorization Act of 1992, Public Law 102-564; and the Small Business Administration's (SBA) SBIR Policy Directive. SBIR has been established in 11 Federal agencies. Phase I is a 6-month feasibility research project that establishes eligibility for Phase II. Phase II is the principal research effort. Phase III is to be conducted with non-SBIR and usually non-Federal funds to pursue commercial applications of the research funded in Phases I and II.

Because the program is intended to increase the use of small business firms in Federal R&D, in ***Phase I a minimum of two-thirds of the research and/or analytical effort must be performed by the proposing firm; in Phase II a minimum of one-half of the research and/or analytical effort must be performed by the proposing firm.***

1.2. The NSF SBIR Program

The primary objective of the NSF Program is to increase the incentive and opportunity for small firms to undertake cutting-edge, high-risk, high-quality scientific, engineering, or science education research that would have a high potential for economic payoff if the research is successful. Additional objectives include stimulating technological innovation in the private sector, increasing the commercial application of NSF-supported research, and improving the return on investment from Federally funded research for its economic and social benefits to the nation. The proposed research must be responsive to the NSF program interests stated in the topic descriptions of this solicitation.

NSF does not normally support bioscience research with disease-related goals, including work on the etiology, diagnosis, or treatment of physical or mental disease, abnormality, or malfunction in human beings or animals. Animals models of such conditions or the development or testing of drugs or other procedures for their treatment

also are not eligible for support. However, research in bioengineering, with diagnosis or treatment-related goals, that applies engineering principles to problems in biology and medicine while advancing engineering knowledge is eligible for support. Bioengineering research to aid persons with disabilities is also eligible, as are biomedical applications in certain areas of microelectronic information processing. Proposals for technical assistance, pilot plant efforts, research requiring security classification, demonstration projects, product development, or market research for a particular product or invention are normally not supported.

The objective of Phase III follow-on funding is to support development efforts using non-SBIR and usually non-Federal funding for commercial application of the research supported by NSF under Phases I and II.

This solicitation is for Phase I proposals only. It does, however, provide the basis for any Phase II proposals resulting from Phase I awards. The SBIR Program is not a substitute for existing unsolicited proposal mechanisms used in other NSF programs. Unsolicited proposals will not be accepted under the SBIR Program in either Phase I or Phase II.

1.3. Program Emphasis for 1994—National Critical Technologies

The NSF SBIR Program encourages proposals across all fields of science and engineering supported by the Foundation (see Section 11, *Research Topic Descriptions*). Within that framework, the following critical technology areas of national importance are emphasized:

- Applied Molecular Biology
- Distributed Computing and Telecommunications
- Electricity Supply and Distribution
- Flexible Integrated Manufacturing
- Materials Synthesis and Processing
- Microelectronics and Optoelectronics
- Pollution Minimization and Remediation
- Software
- Transportation

When proposals are otherwise considered to be of approximately equal technical merit, proposals in these areas may be given additional consideration in the evaluation process.

1.4. Phase I—Feasibility Research

Phase I is a 6-month experimental or theoretical investigation on the proposed innovative idea or approach.

Phase I should determine insofar as possible:

- the probable technical feasibility of the proposed idea; and
- the ability to produce significant results before consideration of additional Federal support in a Phase II project.

The work proposed for Phase I should be suitable in nature for subsequent progression to Phases II and III. Contingent upon the success of the research in Phase I, the ultimate aim of the research should be to develop commercial products, processes, or techniques. The Principal Investigator should approach the SBIR Program with the objective of bringing the project to fruition in Phase III, through the Phase II effort.

Under this solicitation NSF anticipates that it will make about 280 Phase I awards of up to $65,000 each. Research results are to be submitted to NSF in a comprehensive Phase I Final Report.

The required Phase I Final Report is due at the end of the 6-month performance period.

1.5. Phase II—Principal Research Project

Phase II is the principal research effort that builds on the feasibility research project undertaken in Phase I. Only

the successful completion of a Phase I award makes the awardee eligible to submit a single Phase II proposal. Phase II proposals can be submitted only to the particular Federal agency that awarded Phase I of the effort.

NSF makes every effort to make timely award decisions. For administrative reasons, Phase II award decisions may be delayed considerably unless the following schedule is met.

1. The Phase I Final Report is received within 15 days of the end of the 6-month performance period of Phase I, and;

2. The Phase II proposal is received within 30 days of the Phase I Final Report.

Phase II proposals should be prepared in accordance with instructions that NSF will provide to all Phase I grantees prior to the end of Phase I. (See *Schedule*, Section 3.1, and *Phase I Final Report*, Section 7.2.A.)

Phase II awards for up to $300,000 and for 24 months will be made to those small businesses with projects that appear most promising. It is anticipated that approximately one-third of the Phase I awardees will receive Phase II grants.

Resubmission of a declined Phase II proposal is not permitted.

1.6. Supplement to Funding of Phase I Awards

As part of the Phase I Final Report, the proposer will be asked to declare whether he/she will be submitting a Phase II proposal. In the event that the proposer concludes that the success of the Phase I project warrants an application for a Phase II effort, he/she may be given an opportunity to receive a supplement to Phase I funding to increase the effectiveness of the project by maintaining its continuity.

Not all projects will be eligible to receive a supplement to Phase I funding. Requests for supplemental funding will be awarded based on the following criteria.

1. The Phase I Final Report **must** be received within 15 days of the end of the 6-month performance period of Phase I.

2. The budget for a supplement to Phase I funding may be for a period of up to 3 months, not to exceed $10,000. (Items in the supplemental budget must conform to the requirements for Phase I.)

3. The Phase II proposal along with the budget for the supplement to Phase I funding **must** be received within 30 days of the submission of the Phase I Final Report. The requested start date for the supplement may not be earlier than October 15.

4. The acceptance by NSF of the Phase I Final Report.

Supplements to Phase I funding will be granted to all requests that meet the above criteria.

The deadlines indicated under criteria 1 and 3 are firm.

If a project is ineligible for a supplement to Phase I funding, the grantee will still be permitted to submit a Phase II proposal.

1.7. Phase III—Commercial Applications

The objective of Phase III is to pursue commercial applications from the government-funded research to stimulate technological innovation and improve the return on investment from Federally-funded research for its economic and social benefits to the nation. Phase III is to be conducted with non-SBIR funds (either Federal or non-Federal). NSF normally will not fund Phase III efforts.

2. ELIGIBILITY

2.1. Eligibility of Firm

A proposing firm must qualify under the definition of small business given in Section 4.5 of this solicitation. Proposals from joint ventures and partnerships are permitted, provided the entity created qualifies as a small business in accordance with this solicitation. ***To be eligible, a minimum of two-thirds of the research and/or analytical effort as determined by budget expenditures must be performed by the proposing firm during Phase I, and a minimum of one-half of the research and/or analytical effort must be performed by the proposing firm during Phase II.***

In both Phases I and II, all research must be performed in the United States. "United States" means the 50 states, the territories and possessions of the United States, the Commonwealth of Puerto Rico, the Commonwealth of the Northern Mariana Islands, the Trust Territory of the Pacific Islands, and the District of Columbia.

2.2. Eligibility of Principal Investigator

The NSF SBIR Program is designed to support small businesses. For both Phase I and II, the primary employment of the Principal Investigator must be with the small business firm at the time of award and during the conduct of the proposed effort. Primary employment means that more than one-half of the Principal Investigator's time is spent in the employ of the small business. **Primary employment with a small business precludes full-time employment at another organization.**

If the individual who is proposed as the Principal Investigator is not a U.S. citizen, he/she must legally reside in the U.S. and be legally empowered to work in the U.S. at the time that an award is made. ***Proposed Principal Investigators who are not U.S. citizens are urged to consult with an NSF SBIR Program Director concerning their eligibility.***

The individual who is proposed as the Principal Investigator at the time of the submission of the Phase I proposal is expected to be the Principal Investigator at the time of the inception of the Phase I award. A change in Principal Investigator prior to an award could affect whether an award will be made. It is also expected that the Principal Investigator on a Phase II project will be the same individual as the Principal Investigator on Phase I. ***Any changes of the Principal Investigator must be requested in writing to Office Head, Industrial Innovation and Partnerships, Room 590, National Science Foundation, 4201 Wilson Boulevard, Arlington, VA 22230, and must be approved by the Grants Officer.***

A. Academic Affiliation—An individual who is employed by, or who has full-time student status with, an academic institution may serve as the Principal Investigator only if that individual

- plans to take full-time leave from the academic institution to become eligible for an SBIR award, and
- provides a statement from the institution approving the proposed Principal Investigator's release from employment for the full Phase I period of performance and for the full Phase II period of performance, if a Phase II award is made. **This statement must be signed by the Department Head and an Authorized Organizational Representative of the institution.**

The above statement approving release from employment at an academic institution must be included as part of the Phase I proposal.

Any proposed Principal Investigator whose employment at an academic institution will terminate before the award date should make an explicit statement to that effect in the proposal.

A proposed Principal Investigator who maintains full-time employment in a small firm and who teaches not more than one course per term at an academic institution may submit, instead of the above, a statement from an authorized representative of the academic institution certifying that the said Principal

Investigator is not eligible to submit a proposal to NSF through the academic institution.

Principal Investigators who are employed by an academic institution—whether as full-time or part-time employees, tenured professors, adjunct professors, emeritus professors, consulting professors, lecturers, research associates, research scientists, students, or any other category of academic employment—are urged to consult with an NSF SBIR Program Director on any question about their eligibility prior to submitting a proposal.

B. Research Support through an Academic Institution—It is the policy of NSF that an individual serving as a Principal Investigator on an SBIR award may not receive research support through an academic institution, regardless of whether the source of that support is public or private. Therefore, an individual who is receiving research support through an academic institution must terminate such support prior to serving as the Principal Investigator on an SBIR award. In addition, that individual must withdraw any pending proposals submitted through an academic institution prior to receiving an SBIR award. Contractual or other commercial arrangements with an academic institution, however, are permitted.

C. Other Employment—Proposed Principal Investigators who are not primarily employed by the small firm or by an academic institution at the time the proposal is submitted must demonstrate how they will meet the eligibility requirements. **Letters pertaining to leave or certifications of intent to become full-time employees of the firm must be included in the proposal.**

3. SCHEDULE

3.1. Phase I

Proposal Due at NSF	by June 13, 1994
Notification by NSF of Receipt of Proposal	by July 11, 1994
Mail Notification by NSF of Awards and Declinations	approx. December 31, 1994
Phase I Final Report at NSF	due at the end of the 6-month period of performance

3.2. Phase I Supplement

Request Due at NSF	within 30 days after submission of a Phase I Final Report

3.3. Phase II

Instructions from NSF for Preparing Phase II Proposals	by May 15, 1995
Proposal Due at NSF	within 30 days after submission of a Phase I Final Report

4. DEFINITIONS

The following definitions apply for the purposes of this solicitation.

4.1. Principal Investigator

The Code of Federal Regulations, Title 42, Part 52, defines a Principal Investigator as "the single individual designated by the grantee in a grant application...who is responsible for the scientific and technical direction of the project."

4.2. Research

Any activity that is a systematic, intensive study directed toward greater knowledge or understanding of the subject studied or a systematic study directed specifically toward applying new knowledge to meet a recognized need.

4.3. Development

A systematic application of knowledge toward the production of useful materials, devices, and systems or methods, including design, development, and improvement of prototypes and new processes to meet specific requirements.

4.4. Subcontract

Any agreement, other than one involving an employer-employee relationship, entered into by a Federal Government funding agreement awardee calling for supplies or services required solely for the performance of the original funding agreement.

4.5. Small Business

A business concern that at the time of Phase I and Phase II awards meets the following criteria.

1. It is independently owned and operated, is not dominant in the field of operation in which it is proposing, has its principal place of business located in the United States, and is organized for profit.

2. It is at least 51 percent owned, or in the case of a publicly owned business, at least 51 percent of its voting stock is owned, by United States citizens or lawfully admitted permanent resident aliens.

3. It has, including its affiliates, ***a number of employees not exceeding 500***, and meets the other regulatory requirements found in 13 CFR Part 121. Business concerns, other than investment companies licensed, or state development companies qualifying under the Small Business Investment Act of 1938, 15 U.S.C. 661, et seq., are affiliates of one another when either directly or indirectly, (a) one concern controls or has the power to control the other; or (b) third parties (or party) control(s) or has the power to control both. Control can be exercised through common ownership, common management, and contractual relationships. The term "affiliates" is defined in great detail in 13 CFR 121.3-2(a). The term "number of employees" is defined in 13 CFR 121.3-2(t). Business concerns include, but are not limited to, any individual, partnership, corporation, joint venture, association, or cooperative.

4.6. Socially and Economically Disadvantaged Small Business

A socially and economically disadvantaged small business concern is one

- that is at least 51 percent owned by either a Native American tribe or a native Hawaiian organization, or by one or more socially and economically disadvantaged individuals, and

- whose management and daily business operations are controlled by one or more of such individuals.

A socially and economically disadvantaged individual is defined as a member of any of the following groups:

- Black Americans
- Hispanic Americans
- Native Americans
- Asian-Pacific Americans
- Subcontinent Asian Americans
- Other groups designated from time to time by SBA to be socially disadvantaged
- Any other individual found to be socially and economically disadvantaged by SBA pursuant to Section 8(a) of the Small Business Act, 15 U.S.C. 637(a).

4.7. Women-Owned Small Business

A small business that is at least 51 percent owned by a woman or women who also control and operate it is women-owned. "Control" in this context means exercising the power to make policy decisions. "Operate" in this context means being actively involved in the day-to-day management.

5. SELECTION PROCESS AND EVALUATION CRITERIA

Proposals will be screened to determine responsiveness to the specific requirements of the solicitation. Proposals passing this screening will then be technically evaluated to determine those with the most promising approaches. Each proposal will be evaluated on its merits and judged on a competitive basis. NSF is under no obligation to fund any proposal or any specific number of proposals on a given topic.

5.1. Administrative Screening

Before a proposal can be submitted to merit review, it must meet the requirements described in Section 6, *Phase I Proposal Preparation Instructions and Requirements.* NSF will review each proposal to determine that it satisfies all requirements.

Proposers are advised that failure to satisfy any one of these requirements will render a proposal **nonresponsive** to this solicitation. Nonresponsive proposals will be returned to the proposer without further consideration.

5.2. Merit Review

Proposals that are found to be responsive will be competitively evaluated in a process of external merit review by scientists, engineers, or educators knowledgeable in the appropriate field. Most reviewers are employed by universities or the Federal Government. Others may be employees of nonprofit research laboratories, recent retirees from industrial firms, and, on occasion, employees of industrial organizations, including small business concerns. In all instances, proposals will be handled on a confidential basis, and care will be taken to avoid conflicts of interest. Evaluations will be confidential to NSF, to the proposed Principal Investigator, and to the submitting small business concern, to the extent permitted by law.

In the Phase I merit review process, approximately equal consideration will be given to each of the following five criteria.

1. The scientific/engineering quality of the proposed research.

2. The soundness of the research plan to establish the probable technical feasibility of the concept.

3. The uniqueness/ingenuity of the proposed concept or application as technological innovation.

4. The potential of the proposed concept for commercial applications.

5. The qualifications of the Principal Investigator, other key staff, and consultants in relation to the proposed research; the time commitment of the Principal Investigator; and the availability of instrumentation and facilities.

5.3. Selection for Award

Normally, more Phase I proposals will be found technically meritorious than can be supported.

Evaluation scores and comments from review panels and/or external reviewers are advisory to the cognizant program officer who makes recommendations on each proposal. Recommended proposals are ranked by the panels and the recommending officer after comparison with other proposals received on the same topic or category. Technically recommended proposals are then reviewed by SBIR program officers who consider past performance, commercial potential, emphasis areas, program balance, and other factors in addition to the technical ranking. The SBIR Program then makes its recommendations for awards.

5.4. Debriefing

When an award or declination is made, verbatim copies of reviews, excluding the names of the reviewers; summaries of review panel deliberations, if any; a description of the process by which the proposal was reviewed; and the context of the decision (such as the number of proposals and award recommendations, and information about budget availability) are mailed to the Principal Investigator.

6. PHASE I PROPOSAL PREPARATION INSTRUCTIONS AND REQUIREMENTS

6.1. Contact with NSF

Questions about the NSF SBIR Program such as the eligibility of the Principal Investigator and administrative concerns may be addressed to: SBIR Program Director, Office of Industrial Innovation and Partnerships, Room 590, National Science Foundation, 4201 Wilson Boulevard, Arlington, VA 22230, telephone (703) 306-1391.

For reasons of competitive fairness, other contact with NSF regarding this solicitation is restricted during the proposal preparation period. In particular, questions concerning the scientific and engineering aspects of the research topics will not entertained.

Requests for copies of the solicitation may be addressed to the SBIR Program at the above address. The solicitation may also be downloaded onto a PC via STIS (The Science and Technology Information System at NSF). (See page following the title page of this solicitation for information on how to use STIS.)

A recorded message that gives the status of the solicitation with regard to NSF's proposal processing and other appropriate information can be reached by calling, toll-free, 1-800-999-7973.

6.2. Proposal Preparation

A particular proposal must be assigned to **one, and only one**, of the numbered topics listed in Section 11, *Research Topic Descriptions*, in this solicitation. This topic number and, if applicable, the appropriate subtopic letter, must be identified on the cover sheet. A firm may submit separate proposals on different topics or different proposals on the same topic under this solicitation.

Proposals may respond to any of the topics or to specific subtopics. ***If equivalent proposals are submitted to different topics, all proposals will be returned without further consideration.***

The Phase I proposal is limited to a total of 25 consecutively numbered pages (single- or double-spaced) **including** Cover Page, Project Summary, main text, references, all other enclosures or attachments (except those specifically excluded from the page count, see A, B, and O in Section 6.3 below), and the Summary Proposal Budget. **Appendices, publications, details of subcontracts, and the second side of any two-sided page other than the Cover Page are included in the page count.**

Pages must be of standard size. Metric size A4 (210 mm X 297 mm) is preferred. 8 1/2" X 11"(216 mm X 279 mm) may be used. In either case, margins not less than 25 mm and type no smaller than 12-point font size must be used, except as legends on reduced drawings, but not tables). Supplementary materials, revisions, and substitutions will not be accepted for administrative reasons and in the interest of equitable treatment for all. ***Proposals not meeting these requirements will be returned without further consideration.***

When responding to this solicitation, use the metric system of weights and measures, unless impractical or inefficient.

A proposal must contain adequate information to be reviewed as research. NSF reserves the right not to submit to technical review any proposal that it finds to have insufficient scientific or technical information.

6.3. Phase I Proposal Format

The proposal must include **all** of the following items in the order shown. NSF forms may be photocopied as required; however, one proposal should contain original signatures and should be clearly marked as the original.

A. NSF Form 1225 (Appendix A)—This form should precede the cover page of the original copy of the proposal only. This form is **not** included in the page count for the proposal nor does it go to reviewers.

B. Cover Page (Appendix B)—Complete this form and use as **page 1** of the original and each copy of the proposal. The back side of this form, the **Certification Page**, must be completed and fully signed and included

only with the original copy of the proposal; it should **not** be included with any of the other copies of the proposal. Please note, the Cover Page is included in the proposal page count; but the Certification Page is **not** included in the proposal page count.

The **period of performance** of Phase I will not exceed 6 months with a proposed start date of January 1, 1995. In cases where the research is better served, a later start date may be requested.

The **title** of the proposal should be brief, technically valid, intelligible to the nonscientist, and suitable for use in the public press. NSF may edit the title of the project before making an award.

C. Project Summary (Appendix C)—Complete this Form and use as **page 2** for all copies of each proposal. The Project Summary should be a self-contained description of the project written in a third-person narrative. The summary should begin as follows: "This Small Business Innovation Research Phase I project...." The summary should include a brief identification of the problem or opportunity, the research objectives, a description of the research, and the anticipated results. The last paragraph of the summary should describe the potential commercial applications of the research and any relevance to economic competitiveness. Also, complete the section entitled Key Words. The information on the form should be accurate, informative to other persons working in the same or related fields, and understandable to the nonscientist.

In the event of an award, this information will be made public.

D. Identification and Significance of the Problem or Opportunity—Make a clear summary statement of the specific research problem or opportunity addressed and its importance, including the anticipated benefits to the nation. This section will start **page 3** of your proposal.

E. Background and Technical Approach—Describe in detail the overall background and technical approach to the problem or opportunity and the part that the proposed research plays in attaining results. Review significant and recent research directly related to the proposed effort, including any conducted by others in the field, the Principal Investigator, the proposing firm, or consultants, and indicate how it relates to the proposed research. Include a concise bibliography.

In this section the proposer should take care to highlight the uniqueness/ingenuity of the proposed concept or application as technological innovation. **Significant cost reduction may be an important aspect of technological innovation.**

F. Phase I Research Objectives—List and explain the **specific** objectives to be accomplished in the course of the Phase I research, including the questions it will try to answer to determine the technical feasibility of the proposed approach. Briefly establish the connections with the Phase II research and Phase III efforts.

G. Phase I Research Plan—This section must provide a detailed description of the Phase I research approach. The plan should indicate not only what is planned but how the research will be carried out. The description should include a technical discussion of the proposed concept, the methods planned to achieve each objective or task, and the sequence of experiments, tests, and computations. The research plan should be linked to the objectives and the questions that the Phase I research effort is designed to answer.

Include a discussion of possible problems or extraneous factors that could affect the proposed research and how these problems can be overcome. In other words, anticipate the questions and concerns that reviewers may have in regard to your proposal and respond to them in this section.

Schedules and charts of project staff activities may be useful. Such charts might include each task, scheduled completion dates, and decision points. Also, indicate which tasks are key starting points for Phase II work.

The above Sections, 6.3.D through 6.3.G, relate to the first three review criteria outlined in Section 5.2 above. These three criteria comprise approximately 60 percent of the total score assigned to each proposal.

H. Commercial Potential—NSF will assess the description of the potential applications of the research results in the marketplace and the proposer's plans to market and commercialize them. Delineate the current plan for commercializing the results of the research. This plan should include a brief description of the proposing company, its field of interest, and the commercial applications and market size that the SBIR research is addressing. It should also briefly describe the major competitive products in those fields; any significant advantages the approach has over existing technology in application, performance, technique, efficiency, or cost; and how the small business concern plans to move from research to market, as anticipated at this time.

Proposing firms with prior NSF or other SBIR support should summarize their progress in commercializing that support. Past performance in the commercialization of results may be a consideration in award decisions.

This Section, 6.3.H, directly relates to the fourth review criterion outlined in Section 5.2 above. This criterion represents approximately 20 percent of the total score assigned to each proposal.

I. Principal Investigator and Senior Personnel—This section should be designed to persuade the reviewers that the Principal Investigator and the senior personnel have the qualifications to undertake the research effort. In addition to presenting the qualifications of the Principal Investigator, it should identify the senior personnel who are participating in the Phase I research and describe their qualifications. Provide only **relevant** biographical information for the Principal Investigator and the senior personnel on present and past employment, education, and professional experience. List only relevant publications of the Principal Investigator and the senior personnel and when necessary summarize other contributions to the technical literature not pertinent to this proposal. Pages devoted to vitae are included within the 25-page limit on the proposal.

This section also should establish the eligibility of the Principal Investigators. (See Section 2.2.) Include any required letters and certification.

J. Consultants and Subcontracts—Since a minimum of two-thirds of the research and/or analytical effort as determined by budget expenditures must be performed by the proposing firm during Phase I, it follows that the total of all consultant and subcontract agreements may not exceed **one-third** of the total grant budget.

1. Consultants: Consultants are defined as persons outside the firm named anywhere in the proposal as contributing to the research. Information on qualifications of the consultants, their education, experience, any directly relevant publications, and how their efforts will contribute to the proposal should be presented. Proposers should have in their own files evidence of the commitment of consultants to participate in the project. In addition, proposers should provide a signed statement from each consultant, whether paid or unpaid, confirming his/her availability and commitment, role in the project, and agreed consulting rate, which must not exceed the daily rate paid to a GS-18 or equivalent, currently $443/day, for participation in this project. Such information constitutes supporting evidence that the full complement of essential expertise is in place to carry out the project.

2. Subcontracts: Similarly, where the subcontract involves research, the subcontracting institution **must furnish a letter signed by an appropriate official** describing the programmatic arrangements and confirming its agreed participation in the research with its proposed budget for this participation.

Required documentation for subcontractors must be submitted with this proposal.

Purchases of routine analytical or other routine services from commercial sources are **not** regarded as reportable subcontract activity. No letter is required for such activity. The item—routine analytical or other routine services—should be reported in the Budget (Appendix D) under Other Direct Costs/Other (Item G.6).

K. Equipment, Instrumentation, Computers, and Facilities—A detailed description of necessary equipment, instrumentation, computers, and facilities to carry out that portion of the research and/or analytical effort

that is to be carried out by the proposing firm in Phase I should be provided. **Do not list equipment, instrumentation, computers, and facilities that are not necessary to the proposed project.** If the equipment, instrumentation, computers, and facilities for this research are not the property (owned or leased) of the proposer, an **authorized** official of the organization that owns or controls the facility/equipment **must provide a signed statement certifying** the availability of the facility/equipment, control by the proposing organization, and all costs for the use of the facility/equipment including any associated technician costs.

A copy of this certification must be submitted with the proposal.

> ***The above Sections, 6.3.I. through 6.3.K, relate to the fifth review criterion outlined in Section 5.2 above. This criterion represents approximately 20 percent of the total score assigned to each proposal.***

L. Current and Pending Support of Principal Investigator and Senior Personnel—In this section, the Principal Investigator and senior personnel should show that they have the time available to perform the proposed research during the grant period. Each proposal should provide information about **all** research to which the Principal Investigator and other senior personnel either have committed time or have planned to commit time (in the event that pending projects are supported during the SBIR Phase I period of performance), whether or not salary for the person involved is included in the budgets of the various projects. **If none, report none.**

This information should include the following:

- Titles and dates of current grants or contracts.
- Source of funds for each.
- Person-months devoted to each project by the Principal Investigator and each of the senior personnel during the proposed grant period.
- Identical information for all proposed research that is being considered by or that will be submitted in the near future to other possible sponsors, including other proposals being submitted to the SBIR Program in response to this solicitation and to other Foundation programs.

The current and pending support statement should be included in the proposal at the time of submission. (See Appendix E, Sample Proposal: Section VIII, p. 71, for an acceptable example of a current and pending support statement.)

M. Equivalent Proposals to Other Federal Agencies—A firm may elect to submit proposals that are similar or overlapping in technical content to any other Federal agency. Where an equivalent has already been submitted or **where one will be submitted in the near future** to another Federal Agency, a statement must be included which provides the following information:

1. The name and address of the agencies to which proposals were submitted or will be submitted.

2. Date of proposal submission.

3. Title, number, and date of solicitations under which proposals were submitted or will be submitted.

4. The specific applicable research topics for each SBIR proposal submitted or to be submitted.

5. Titles of the research projects.

6. Name and title of Principal Investigator (Project Director) for each essentially equivalent proposal submitted or to be submitted.

NSF will not make awards that essentially duplicate research funded (or expected to be funded) by other agencies.

If no equivalent proposals are under consideration, state none.

N. Budget (Appendix D)—The NSF Summary Proposal Budget must be used. Complete this form for the Phase I effort only. **Read the reverse side of the budget page and provide the explanation of budget items called for.** Phase I estimates must be shown in detail on this form. ***The budget may not exceed $65,000 (including fee of up to 7%) for the Phase I proposal.*** The budget should reflect cost for work to be done only after the effective date of the award. Please note, an awardee may not expend funds for any costs associated with the project before the award document is signed by the Grants Officer.

The Principal Investigator and senior personnel should be listed by name with their time commitments budgeted in person-months and in dollar amount for the 6-month Phase I performance. ***During the Phase I award performance period, the Principal Investigator must commit at least one person-month to the proposed research effort.***

The reimbursement rates for consultants are a direct cost, which cannot exceed the daily rate paid to a GS-18 or equivalent, currently $443/day. Consultant travel should be shown under the travel category.

Equipment and foreign travel cannot be included in the Phase I budget. Equipment is defined as an article of nonexpendable, tangible personal property, having a useful life of more than two years and an acquisition cost of $500 or more per unit. If Materials and Supplies (Item G.1), on the Budget Form exceeds $2,000, the items should be detailed on a budget explanation page. Total NSF funding may exceed $65,000 only under the conditions described under Facilitation Awards for Scientists and Engineers with Disabilities inside this solicitation cover.

O. Prior Phase II Awards—Firms that have received more than 15 Phase II SBIR awards from all Agencies in the prior 5 fiscal years (October 1, 1988 to September 30, 1993) must submit for each Phase II award:

Name of awarding agency
Date of award
Funding agreement number
Topic or subtopic
Title
Amount
Commercialization status

If a firm has not received more than 15 Phase II awards in the past 5 fiscal years, include a statement to that effect.

Required information on Prior Phase II Awards will not be counted towards the proposal page count.

Provide this information as Attachment I to the original copy only of the proposal.

6.4. Checklist

The Checklist (a perforated page that can be easily removed from the solicitation), which appears as page iii, has been included for your convenience; it should **not** be submitted as part of your proposal.

6.5. Sample Proposal (Appendix E)

A proposal that was submitted under the 1993 SBIR Solicitation and resulted in a Phase I award is provided as a sample in Appendix E. The sample proposal is provided solely for general guidance. Some information has been deleted from the proposal to protect confidentiality.

7. OTHER CONSIDERATIONS

7.1. Awards

NSF anticipates making about 280 Phase I fixed-price grants of up to $65,000 each. Awards normally will be made for the 6-month period of performance, usually January 1 to June 30, 1995.

Reasonable fees (estimated profit) will be considered under both phases of the solicitation. The amount of the fee approved by NSF normally will not exceed 7 percent of total project costs negotiated. Cost-sharing is permitted; however, it is not required nor will it be a factor in the evaluation of a proposal.

Prior to any award, the Foundation may require certain organizational, management, and financial information

for administrative purposes to assure that the applicant adheres to certain business and financial standards. When requested by NSF, this information should be returned to the NSF Division of Grants and Agreements as expeditiously as possible.

7.2. Reports

A. Phase I Final Report—Twelve (12) copies of a comprehensive Phase I Final Report not to exceed 30 pages in length, must be submitted to the Office of Industrial Innovation and Partnerships, Room 590, National Science Foundation, 4201 Wilson Boulevard, Arlington, VA 22230, within 6 months after the start date of the award (unless otherwise stated in the grant letter). The final report shall begin with a verbatim statement of Phase I objectives from the Phase I proposal, a summary description of the research carried out, the research findings or results obtained, and the potential commercial applications of the research. The balance of the report should provide further detail. Additional instructions will be sent to Phase I awardees at a date prior to the scheduled completion of Phase I.

All Phase I Final Reports must carry the following acknowledgement on the cover page: "This material is based upon work supported by the National Science Foundation under award number ___________. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the National Science Foundation."

The Phase I Final Report will be sent by NSF to the National Technical Information Service (NTIS) four years following expiration of the Phase II grant or of the Phase I grant when no Phase II award is made.

The above acknowledgement of NSF support and a disclaimer must appear in publications of any materials, whether copyrighted or not, based on or developed under NSF-supported projects. The disclaimer may be deleted from any articles or papers published in scientific, technical, or professional journals.

B. NSF Form 98A—Within 90 days after the expiration date of a grant, the investigator is required to submit a Final Project Report (NSF Form 98A) to the NSF SBIR Program Officer. **This report form is distinct from, and is not to be confused with, the Phase I Final Report.** NSF will send Form 98A along with a postage-paid self-addressed envelope to each Principal Investigator approximately 30 days prior to the expiration date of a grant. The Form 98A fulfills the second of the two NSF reporting requirements for a Phase I grant. ***A Phase II proposal cannot be processed for an award until this form has been received from the grantee.***

7.3. Payment Schedule

No invoices are necessary under Phase I grants. Phase I payments will be made as follows: one-third approximately 3-4 weeks after the effective date of the award, one-third 3 months after award, and the remainder upon acceptance of a satisfactory Phase I Final Report by NSF. The first two payments are automatic and the final payment will only be made upon receipt and acceptance of the Phase I Final Report.

7.4. Proprietary Information, Inventions, and Patents

A. Proprietary Information—Information contained in unsuccessful proposals will remain the property of the proposer, but NSF will retain file copies of all proposals. Any proposal that is funded will be considered an integral part of the award and will not be made available to the public for 4 years following the completion of Phase I or Phase II.

Proprietary information should be limited. Set proprietary information apart from other text on a separate page, and key it to the text by numbers. Confine it to a few critical technical items that, if disclosed, could jeopardize the obtaining of foreign or domestic patents. Trade secrets, salaries, or other information that could jeopardize commercial competitiveness should be similarly keyed and presented on a separate page.

Proposals or reports that attempt to restrict dissemination of large amounts of information may be found unacceptable by NSF.

Proprietary information submitted to NSF will be treated in confidence to the extent permitted by law if it is confined to a separate page or pages and marked with a legend similar to the following: "Following is proprietary (specify) information which (name of proposing organization) requests not be released to persons outside the Government, except for purposes of evaluation."

Any other legend may be unacceptable to the Foundation and may constitute grounds for return of the proposal without further consideration. Without assuming any liability for inadvertent disclosure, NSF will limit dissemination of such information to its employees and, where necessary for the evaluation of the proposal, to outside reviewers on a confidential basis. Since reports by the Principal Investigator may be made available to the public, such reports shall not contain any restrictive language purporting to limit their use other than for technical data as described below.

B. Rights in Data Developed Under SBIR—Data developed under an SBIR award are furnished with SBIR rights. For a period of 4 years after acceptance of all items to be delivered under this award, either Phase I or Phase II, the Government agrees to use these data for Government purposes only, and they shall not be disclosed outside the Government (including disclosure for procurement purposes) during such period without permission of the contractor, except that, subject to the foregoing use and disclosure prohibitions, such data may be disclosed for use by support contractors. After the aforesaid 4-year period the Government has a royalty-free license to use, and to authorize others to use on its behalf, these data for Government purposes, but it is relieved of all disclosure prohibitions and assumes no liability for unauthorized use of these data by third parties. This Notice shall be affixed to any reproductions of these data, in whole or in part.

7.5. Copyrights

The grantee normally may copyright and publish (consistent with appropriate security considerations, if any) material developed with NSF support. NSF obtains royalty-free license for the Federal Government and requires that each publication contain an acknowledgement and disclaimer statement as shown under section 7.2., *Reports*.

7.6. Patents

Each award agreement will contain a patent rights clause under which small business firms normally may retain the principal worldwide patent rights to any invention made with NSF support. NSF receives a royalty-free license for Federal Government use, reserves the right to require the patent holder to license others in certain circumstances, and requires that anyone exclusively licensed to sell the invention in the United States must normally manufacture it domestically. To the extent authorized by 35 U.S.C. 205, NSF will not make public any disclosure by the grantee of an NSF-supported invention for a 4-year period to allow the grantee a reasonable time to file a patent application. The time period for filing is specified in the patent rights clause and applicable Federal regulations. Additional information may be obtained from the Office of the General Counsel, Room 1265, National Science Foundation, 4201 Wilson Boulevard, Arlington, VA 22230.

7.7. Grantee Commitments

In the event of an award, the awardee will be required to make certain legal commitments through acceptance of the terms and conditions of the Phase I funding agreements. Copies of complete terms and conditions are available upon request.

7.8. Critical Additional Information

A. Management Responsibility—The responsibility for the performance of the Principal Investigator and other employees or consultants who carry out the proposed work lies with the management of the small business concern receiving an award.

B. Accuracy of Information—The proposing small business concern and the Principal Investigator are responsible for the accuracy and validity of all the administrative, fiscal and scientific information in the proposal. Deliberate withholding, falsification, or misrepresentation of information could result in

administrative actions such as declination of a proposal or the suspension and/or termination of an award, as well as possible criminal penalties.

C. Audits—Both Phase I and Phase II awards are subject to Federal audit as specified in the applicable Grant Terms and Conditions.

D. Changes in Organization or Principal Investigator Status—The SBIR Program must be notified promptly if there is any change in the name or address of the firm or if the firm no longer qualifies as a small business. Any change in the Principal Investigator under an active grant must be requested in writing to the Office of Industrial Innovation and Partnerships. (See also, Section 2.2, *Eligibility of Principal Investigator.*)

E. Inconsistencies—This Program Solicitation is intended for informational purposes and reflects current planning. If there is any inconsistency between the information contained herein and the terms of any resulting SBIR grant, the terms of the grant are controlling.

8. SUBMISSION OF PROPOSALS

8.1. Deadline for Proposals

Deadline for receipt (10 copies) at NSF is 5 p.m., EDT, June 13, 1994. Proposals that do not meet the deadline or that do not adhere to other requirements of this solicitation will be returned to the proposer without further consideration.

Proposers are cautioned to be careful of unforeseen delays which can cause late arrival of proposals at the Foundation.

Evaluation and processing will require approximately 6 months for completion, and no information on proposal status will be available until formal notification is made.

8.2 Proposal Submission

Proposals (10 copies) should be addressed to:

Proposal Processing Unit, Room P1-60
NSF Solicitation No. 94-45
4201 Wilson Boulevard
Arlington, VA 22230
ATTN: SBIR Program

A. Packaging—Secure packaging is mandatory. The Foundation cannot be responsible for the processing of proposals damaged in transit. All 10 copies of a proposal shall be sent in the same package. Do not send separate "information" copies or several packages containing parts of a single proposal. **One copy must be signed as an original by the Principal Investigator and the company official.** Other copies may be photocopied.

B. Bindings and Covers—Do not use any special bindings or covers. Staple the pages in the upper left-hand corner of the cover sheet of each proposal.

A recorded message which gives the status of the SBIR solicitation with regard to NSF's proposal processing and appropriate additional information can be heard by calling, toll-free, 1-800-999-7973.

Because of the competitive nature of the solicitation, status information on individual proposals will not be available.

9. PHASE II

9.1. Guidelines for Phase II

Guidelines for submittal of Phase II proposals which are more specific than those noted below will be provided to Phase I awardees by the SBIR Program Director by May 15, 1995. These guidelines will include specific instructions relating to the Phase II award and payment schedules, the demonstration of commercial potential, and the annual commercialization report. Because obtaining an acceptable Phase II follow-on funding commitment may be time

consuming, however, this aspect of commercial potential is outlined below.

9.2. Eligibility

Only those NSF Phase I grantees who successfully complete their awards and submit acceptable Phase I Final Reports are eligible to submit Phase II proposals to NSF. Any change of Principal Investigator between Phase I and Phase II must be requested in writing to the ***Office of Industrial Innovation and Partnerships*. If a Phase II proposal has been declined, it is not eligible for resubmission.**

9.3. Awards and Payment Schedule

The budget request and period of performance in Phase II should depend upon the scope of research proposed but will not normally exceed 24 months and $300,000.

It is anticipated that about one-third (75 to 90) of the Phase I awardees will receive Phase II grants depending upon availability of funds. Phase II awards will be made within approximately 6 months after submission of Phase II proposals.

Phase II awards are expected to be "Firm Fixed Price" with a definitive payment schedule based on receipt and acceptance of required progress reports. Progress reports will reflect technical progress against milestones established in the Phase II proposal.

9.4. Phase II Criteria

In evaluation of Phase II proposals, approximately equal consideration will be given to each of the following criteria.

1. The degree to which the Phase I objectives were met (presented in the Phase I Final Report).

2. The scientific/engineering quality of the proposed research, and the soundness of the research plan to attain a laboratory prototype or equivalent for Phase III product development and commercialization.

3. The uniqueness/ingenuity of the proposed concept or application as technological innovation.

4. The qualifications of the Principal Investigator, other key staff, and consultants relative to the proposed research; the time commitment of the Principal Investigator; and the availability of proposed instrumentation and facilities.

5. Reasonableness of the budget requested for the work proposed.

6. The potential of the proposed concept for commercial applications as evidenced by:

- the small business concern's record of commercializing SBIR or other research;
- the existence of acceptable second phase funding commitments from private sector or non-SBIR funding sources;
- the existence of acceptable third phase follow-on funding commitments for the subject of the research, and;
- the presence of other indicators of commercial potential of the idea.

9.5. Follow-On Funding Commitments

The SBIR Program is designed to provide incentives for the conversion of Federally sponsored research to technological innovation and commercial application. This research can serve as both a technical and preventure capital base for ideas which may have commercial potential. Proposers are asked to consider the commercial possibilities of their research for a wide range of applications. Proposers are encouraged to obtain a contingent commitment for follow-on funding from a third party to pursue further development of the commercial potential without interruption after the completion of the Government-funded research phases. Government funding pays for research related to Federal objectives (SBIR Phases I and II); private or non-SBIR funding pays for development related to commercial objectives (Phase III).

The commitment agreement may be from any of a number of different sources. These include venture capital firms, large companies, joint ventures, R&D limited partnerships, contract research, sales of prototypes, private investors, a recent public offering, state finance programs, or existing investors. Phase III also may involve non-SBIR funded R&D or production commitments with another Federal agency for potential products or processes (resulting from the NSF funded research) intended for use by the United States Government.

A few clearly defined and measurable objectives should be stated in the commitment agreement at the threshold level that would justify private investment if those technical objectives were achieved in Phase II. The objectives do not have to be the same as those stated in the proposal, but they must be attainable within the scope of the proposed Government-funded research.

The commitment agreement should set forth the specific amount of Phase III funds that will be made available to the small firm and indicate the dates the funds will be provided. The commitment may be contingent upon (1) the receipt of a Phase II award; (2) Phase II achievement of certain measurable scientific or technical objectives; (3) the research not being bypassed in the marketplace during Phase II; and (4) the technology appearing to be economically viable. If these objectives are met, the commitment should become exercisable, and the Phase III funding should take place. The terms cannot be contingent upon the obtaining of a patent due to the length of time this process requires. Further information will be provided to Phase I awardees. ***If the commitment is obtained from a foreign firm, it must state that products for the United States market will be manufactured substantially in the United States.***

To receive consideration for the follow-on funding commitment in the evaluation process, a signed contingent commitment between the small business and non-SBIR source of its own choice is required. **The commitment should be consistent with the terms outlined above and should be for a minimum of $200,000.**

9.6. Annual Commercialization Report

Phase II awardees are required to provide an annual commercialization report over the award period, and they may be asked to continue reporting commercial results for 5 years after the award period. The report would include the amount and type of continuing investment obtained to pursue commercialization and any products, sales, royalties, patents, or spinoffs attributable to the SBIR project, as well as changes in the company's employment levels. The purpose of this report is to help monitor the extent of the commercial application derived from SBIR-supported research.

10. SCIENTIFIC AND TECHNICAL INFORMATION SOURCES

When Section 11, *Research Topic Descriptions*, includes references to publications not commercially available, in some instances information on where such publications can be obtained has been included following the commercially unavailable reference.

Proposers also may want to obtain additional scientific and technical information related to their proposed effort as background or for other purposes. Literature searches, abstracts, publications, and the names of potential consultants in the specific research area can be obtained at good technical libraries, some state organizations, and from the organizations listed below. Documents should be ordered soon after receipt of a solicitation as it may take some time to acquire them. To obtain this service or additional information, contact any of the following organizations.

National Technology Transfer Center
316 Washington Avenue
Wheeling, WV 26003
1-800-678-6882

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4600
1-800-553-6847

NSF Research Reports
Capital Systems Group, Inc.
1355 Piccard Drive
Rockville, MD 20850
(301) 216-1168

NASA/Southerny Technology Applications Center
1 Progress Boulevard
Alachua, FL 32615
1-800-472-6785

NASA Far West Regional Technology
Transfer Center
Los Angeles, CA
CA Only 1-800-642-2872
Other 1-800-872-7477

Center for Technology Commercialization, Inc.
100 North Drive
Westborough, MA 01581
(508) 870-0042
1-800-472-6785

NASA Mid-Continent Technology Transfer Center
College Station, TX 77843-8000
1-800-472-6785

The MidAtlantic Technology
Applications Center
823 William Pitt Union
University of Pittsburgh
Pittsburgh, PA 15260
1-800-257-2725

NERAC
1 Technology Drive
Tolland, CT 06084
(203) 872-7000

DIALOG Information Services, Inc.
1-800-334-2564

Chemical Abstract Service
STN International
1-800-753-4227

11. RESEARCH TOPIC DESCRIPTIONS

Small Business Innovation Research (SBIR) proposals are solicited across the full scope of NSF-supported research as defined in the 26 topic descriptions that follow. Subsection A. "Scope of Research" under each topic describes the basic research areas funded by each research division of NSF. Primarily universities and other nonprofit research institutions are recipients of basic research funding. Subsection B. "Suggested Subtopics" describes specific research areas that the divisions think may be appropriate to the SBIR Program. Most topics are also open to other applications-oriented research ideas with commercial potential that are relevant to the topic area. Some topics, however, state that interest is limited to the areas described. Areas of emphasis described in Section 1.3., *Program Emphasis for 1994*, are dispersed throughout the topics.

Note: Some topic descriptions have substantially changed since last year's solicitation. Some topic numbers have also changed; check the assignment of proposals to topic numbers carefully.

If a proposal falls within a topic (numbered 1-26) but not within any of the suggested subtopics (lettered a, b, c, etc.), leave blank the subtopic designation on the cover page of the proposal. Otherwise, enter the letter of the selected subtopic.

1. PHYSICS

A. Scope of Research

The ***Division of Physics*** supports research studying the nature, structure, and interactions of matter and energy at the most basic level in the following program areas of physics: Atomic, Molecular, and Optical Physics; Plasma Physics; Elementary Particle Physics; Gravitational Physics; and Nuclear Physics. Proposals addressing topics in physics should include the applications of basic concepts in physics in innovative ways to problems in such applied areas as manufacturing, diagnostics, communication, or control. Proposals may be submitted in any subject that falls into the above scope of the Division of Physics. ***[NOTE: Condensed Matter Physics and Materials Research are included in the Division of Materials Research; proposals based principally on work in those fields should be addressed to Topic 3.]*** The feasibility of devices or systems, including associated software, having applications in a broad range of scientific and industrial applications can be considered.

B. Suggested Subtopics

The following are some appropriate subtopics for SBIR projects in physics. This list is meant to be illustrative; proposals are not necessarily limited to these subtopics.

a. Optical Devices—Instruments for control or use of light at the classical or quantum level, using new developments in atomic and optical physics.

b. Electron, Ion, and X-Ray Sources—High-intensity, high-current, high-luminosity sources of radiation, steady-state or pulsed. Development of new or special-purpose accelerators, such as compact, high-gradient, or high-current devices.

c. Particle Detectors—Development of new or significantly improved particle detectors, including high efficiency, damage resistance, good energy resolution, good spatial resolution, or other special-purpose detectors.

d. Electronics—Analog or digital instruments for measurements in the above subfields of physics, with such improvements as fast response, low noise, or novel utilization of principles.

e. Data Processing Systems—Development and application of hardware (such as new, high-performance data acquisition systems, processors, or I/O devices) and/or software (such as data analysis and simulation techniques), derived from research programs in the areas of physics listed above under "Scope of Research."

f. Particle Traps—Application of electromagnetic or optical traps for confinement, study, and manipulation

of elementary particles, ions, neutral atoms, clusters of atoms, or biological cells.

2. CHEMISTRY

A. Scope of Research

The ***Division of Chemistry*** supports research in synthesis, structure, reactivity, energetics, and composition of matter in the following programs: Analytical and Surface Chemistry; Organic and Macromolecular Chemistry; Inorganic, Bioinorganic, and Organometallic Chemistry; and Experimental, Theoretical, and Computational Physical Chemistry. Particular attention is drawn to opportunities for chemistry to provide solutions to major problems in environmental, materials, and biological areas.

It should also be noted that certain aspects of chemistry research are supported by other programs in the Foundation including: Polymers and Solid State Chemistry in the Division of Materials Research; Biochemistry and Biophysics in the Division of Molecular and Cellular Biosciences; Atmospheric Chemistry in the Division of Atmospheric Sciences; Geochemistry in the Division of Earth Sciences; Marine Chemistry in the Division of Ocean Sciences; and several programs in the Division of Chemical and Transport Systems in the Engineering Directorate.

B. Suggested Subtopics

The Division of Chemistry has a special interest in fostering the unique interdisciplinary capabilities of small businesses to promote new developments in chemistry and chemical technology. These research activities should be directed logically toward the Phase III development of a marketable product. SBIR projects that involve the research programs in the Chemistry Division typically fall into three general categories. These are broadly defined areas and are not exclusive of any other research having the potential to advance the understanding and utility of chemistry.

a. Chemical Synthesis—Design and synthesis of new organic and inorganic substances that possess unusual properties that give rise to new and improved properties or enable the testing of theoretical, mechanistic, or structural hypotheses. Examples include but are not restricted to

- Molecular-level approaches to the synthesis of organic, inorganic, and organometallic molecules that are useful materials or materials precursors.

- Isolation and characterization of natural products that have well-defined commercial potential.

- Design and synthesis of molecular arrays of importance to molecular recognition, catalysis, separations science, and other interfacial and biomimetic processes.

- Development of environmentally benign synthetic routes for the production of commercially important chemical products.

- Electrosynthesis of value-added products offering advantages in materials cost, energy utilization, and reduced environmental impact.

- Applications of chemistry in biotechnology and biotechnology in chemistry, e.g., modification or immobilization of proteins for chemical applications.

b. Chemical Characterization—Physicochemical studies leading to the development of a marketable product or procedure for the improved characterization of chemical systems. Such products and procedures often utilize new technologies and may demonstrate new concepts for chemical instrumentation.

- New or improved chemical instruments and sensors having applications in chemistry, biotechnology, or environmental sciences.

- Strategies and devices for characterization of real-world samples in the nanoscale regime and beyond.

- New approaches for the characterization of surfaces and interfaces.

- Comprehensive approaches to maximizing the information content of chemical data.

c. Computational Chemistry—Innovative approaches to computation in the chemical sciences.

- New or improved algorithms for chemical computation.
- Development of graphical user interfaces for computational chemistry software.
- Porting and development of new algorithms for chemical computation on emerging parallel architecture computing platforms.
- Development of improved force field parameterizations for molecular simulations.

References

National Science Foundation. 1993. Guide to programs—fiscal year 1994. NSF 93-167. Washington, DC: NSF.

National Science Foundation. 1992. Environmentally benign chemical synthesis and processing. NSF 92-13. Washington, DC: NSF.

National Science Foundation. 1991. Biomolecular materials. NSF 91-142. Washington, DC: NSF.

National Science Foundation. 1991. Research in electrochemical synthesis. NSF 91-108. Washington, DC: NSF.

National Science Foundation. 1991. Biotechnology opportunities: the NSF role. NSF 91-56. Washington, DC: NSF.

National Science Foundation. 1990. Grant opportunities for chemists. NSF 90-142. Washington, DC: NSF.

3. MATERIALS RESEARCH

A. Scope of Research

The ***Division of Materials Research*** supports research on both the physics and chemistry of materials necessary to develop new materials with superior properties and the interrelationships among synthesis and processing, structure and composition, and properties and performance of materials at molecular, microscopic, and macroscopic levels. New approaches to materials synthesis and processing and to the full range of physical, chemical, and mechanical properties are relevant, but particular interest exists in those properties potentially important to structures, devices, and machines. A wide range of materials is of interest including: electronic, photonic, and optical materials; structural materials; biomolecular materials; and superconducting materials. Excluded from consideration, however, are wood, coal, and waste materials, mineral processing, and extractive metallurgy.

B. Suggested Subtopics

Appropriate subtopics for SBIR proposals are included in the general range of research supported by the Division of Materials Research as indicated by the following program areas: Condensed Matter Physics; Solid-State Chemistry and Polymers; Materials Theory; Metallurgy, Ceramics, and Electronic Materials; and Instrumentation. Among the subtopics of possible interest, the following are highlighted.

a. Instrumentation—Efforts to develop new instrumentation capabilities or to significantly improve existing instrumentation for purposes such as characterizing

- The structure of materials including local and long-range order, symmetries, and the arrangements of constituents on the atomic and large scales.
- The optical, electronic, and magnetic properties of materials under various conditions of excitation and environment.

- Thermal and mechanical properties of materials under a variety of conditions.

- The coupling and relationships among the various properties.

- The nature of surfaces and interfaces particularly as related to structural, mechanical, thermal, optical, electronic, and magnetic properties.

b. Synthesis and Processing of Advanced Materials—

- Novel materials with hierarchical structures.

- Superior matrix materials (with respect to thermal or mechanical properties, or processing ease), reinforcing agents (including high-modulus fibers), or coupling agents for polymer composites.

- Superconducting materials.

- Advanced materials of high quality and reproducibility, with superior properties for potential applications, obtained through control of chemistry, morphology, microstructure, and processing variables.

- Novel materials for electronic, optical, magnetic, and other potential high-technology applications.

- New ceramic materials with superior strength, electrical properties, etc., to replace scarce, strategically important metals and their alloys.

- Specialty advanced materials amenable to high-speed, automated processing or for potential use in materials forming, shaping, and/or removal.

- Artificially structured materials, such as electronic materials, composites, coatings, and phase-separated systems.

Reference

National Research Council. 1989. Materials science and engineering for the 1990's: Maintaining competitiveness in the age of materials. Washington, DC: National Academy Press. [National Academy Press, 2101 Constitution Avenue, NW, Washington, DC 20418.]

4. MATHEMATICAL SCIENCES

A. Scope of Research

The objectives of the ***Division of Mathematical Sciences*** research programs are to foster the creation of new mathematical knowledge and to promote its application to foster a better understanding of physical, biological, and social phenomena. The first of these objectives is achieved by the creation of new mathematical structures and techniques and the analysis and study of relations that exist between them. The second objective is achieved by translating phenomena of the physical, engineering, biological, environmental, and social sciences into mathematical models and then finding solutions to the mathematical problems so formulated through the development of new mathematics as necessary. Programs in Classical, Modern, and Geometric Analysis; Topology and Foundations; Algebra and Number Theory; Applied Mathematics; Computational Mathematics; and Statistics and Probability cover all aspects of the mathematical sciences, from the classification of abstract algebraic structures to equations modeling industrial processes.

The mathematical sciences play a significant role in many of the interdisciplinary initiatives currently being emphasized at the Federal or Foundation level. These include the following: Global Change, High-Performance Computing and Communications, Mathematics and Science Education, Advanced Materials and Processing, Biotechnology, Advanced Intelligent Manufacturing Systems, and Environmental Sciences. Small businesses with interests in research, the development of mathematical models, or algorithm development for these interdisciplinary areas are encouraged to explore these possibilities.

B. Suggested Subtopics

Examples of research activities of substantial interest under the above programs that would be appropriate topics for SBIR proposals include but are not limited to the following:

a. Analytic Methods—

- Flows including properties of dusty gases, flow of oil and water in porous media, flow of slurries in pipes, blood flow, flows with chemistry, and multiphase flows.

- Optimal design including minimal weight structures, drag reduction, optimal composition of composite materials, and optimal shape design.

- Systems theory including parameter identification and control of nonlinear and/or distributed parameter systems, nonlinear filtering, stochastic control, and discrete event control.

- Phenomena involving multiple scales including vortex structures in turbulent flows, polymer shapes, combustion, phase transition, and quantum optics.

- Inverse problems including tomography, NMR, geophysical prospecting, conductivity, and nondestructive evaluation.

- Nonlinear continuum mechanics including multivariate splines, large deformations in elastic materials, crack formation, and turbulent fluid flow.

- Nonlinear optimization and optimal control.

b. Algebraic Methods—

- Mathematical coding theory and cryptology.

- Combinatorial complexity including algorithms, computer codes, and large scale combinatorial optimization.

- Combinatorics including computation and algorithms.

- Symbolic computation.

c. Statistical Methods—

- Optimal design including design for multifactor general linear models, for response surfaces, for robust inference, for nonparametric and semiparametric models, and including adaptive design.

- Statistical computation and algorithms and Monte Carlo and probabilistic problem solving.

- Statistical graphics including graphical methods for high dimensional data, visualization, image reconstruction, curve and surface fitting, and pattern recognition.

- Statistical modeling including nonparametric and semiparametric modeling, modeling for unequal probability samples and unequal spacings, predictive modeling and expressions of model uncertainty, Bayesian modeling of opinion and data, and modeling expert systems.

- Inferential methods such as robust procedures including re-sampling, and detection of change point phenomena.

- Spatial statistics including modeling and mapping techniques, inference for remotely sensed data, and spatial time series analysis.

- Statistical reliability including inference for truncated observations and data with informative censoring, statistical process control.

d. Geometric Methods—

- Geometry of robotic devices.

- Geometry of DNA and polymer structures.

- Integral geometry, geometric probability, stochastic geometry, and pattern recognition.

- Packing and tiling.

- Geometric modeling for CAD/CAM.

- Computational geometry.

- Development and application of fractal techniques.

e. Stochastic Models—Construction, analytical, and algorithmic development and validation of stochastic models with emphasis on realistic, data-driven models developed in close consultation with experts in areas such as biological systems, ecology, environmental systems, geosciences, atmospheric sciences, materials science, and social sciences.

f. Computational Mathematics—Design and development of symbolic and numeric algorithms that better exploit current and future technological developments related to simulation and computation. The focus is on development of critical computational techniques from algorithm development through implementation. Interest ranges over various subjects including dynamical systems, computational fluid dynamics, computer graphics and the mathematics of visualization, parallel computing, symbolic computation, and computational statistics.

References

National Research Council. 1991. Applications of the mathematical sciences to materials science: Report of the Panel on the Mathematical Sciences Applied to Materials Science, Board on Mathematical Sciences. Washington, DC: NRC.

National Research Council. 1991. Mathematical foundations of high-performance computing and communications: Report of the Panel on Mathematical Sciences in High-Performance Computing and Communications, Board on Mathematical Sciences. Washington, DC: NRC.

National Research Council. 1991. Mathematical sciences, technology, and economic competitiveness: Report of the Board on Mathematical Sciences. Washington, DC: NRC.

5. ASTRONOMY

A. Scope of Research

The ***Division of Astronomical Sciences*** supports research to increase understanding of the origin of the universe, its structure, and its energy sources. Research on instrumentation supporting these objectives is also funded.

B. Suggested Subtopics

In astronomical research there is a general need for instrumentation including detectors, imaging systems, and data handling and analysis systems. **Only instrumentation proposals will be considered under this topic.** Research subtopics in instrumentation include but are not limited to the following:

a. Visible Detector Arrays—Research is needed to decrease the cost of high-performance, solid-state detector arrays, such as charge coupled devices (CCDs), for use in the visible region of the spectrum. Of prime importance is an increase in blue sensitivity with dimensionality greater than 1000 x 1000 pixels.

b. Infrared Detector Arrays—Arrays of detectors that are sensitive in the atmospheric transmission windows at wavelengths longer than one micron are required. These arrays need to be of very low noise equivalent power (NEP) and to be capable of operation in the high thermal-radiation background typical of ground-based infrared observations.

c. Fast-Framing Arrays—Visible and infrared arrays, with a frame rate greater than 500 frames per second and dimensionality of 64 x 64 to 128 x 128 elements are needed for wavefront sensing in adaptive optical systems. Read noise for these devices must be less than 10 electrons per second per pixel.

d. Millimeter Wavelength Instrumentation—Further development is needed in the technologies for the fabrication of receivers and coherent mixers used in the millimeter and submillimeter wavelength regions. Techniques to assemble arrays of such detectors are desirable to increase mapping efficiency.

e. Systems for Data Handling and Analysis—Development of systems capable of handling the very large quantities of data provided by various astronomical instruments and providing the user with sophisticated interactive display capabilities is desired.

f. Active and Adaptive Optical Systems—Development of systems that apply recent concepts such as adaptive optics, interferometry, and artificial guide stars to compensate for atmospheric and instrumental blurring in astronomical imaging systems is needed.

Reference

Astronomy and Astrophysics Survey Committee. 1991. The decade of discovery in astronomy and astrophysics. Committee report. Washington, DC: National Academy Press.

6. ATMOSPHERIC SCIENCES

A. Scope of Research

The *Division of Atmospheric Sciences* supports research devoted to physical, dynamical, chemical, and electromagnetic processes that determine the behavior of the earth's atmosphere and the geospace environment from the upper atmosphere to the sun. This includes the following: climate and its variations; the general circulation; synoptic, mesoscale, and microscale weather phenomena; the chemical composition and the cycle of species in the earth's atmosphere; remote sensing of the geospace environment and sun; dynamics of the upper atmosphere; physics of the ionosphere, magnetosphere, and sun; and solar-terrestrial interactions. In addition, the Division supports the acquisition of observations and the development of instrumentation necessary to obtain them.

B. Suggested Subtopics

Proposals are solicited in all of the above research areas. Specific opportunities include but are not limited to the following subtopics:

a. Measurement of Physical Properties—There is a need for improved instruments for remote and *in situ* measurement of precipitation, cloud characteristics, air motion, water vapor, and atmospheric electricity, as well as instruments for ground-based space science.

b. Measurements of Chemical Properties—New techniques are needed for quantitative determination of trace species in the ambient atmosphere, including both rapid and ultrasensitive measurement of transitory species concentrations and fluxes.

c. Analytical and Statistical Methods—Development of analytical and statistical techniques for the processing of and information extraction from very high volume data sources such as remote sensing satellites, radars, and model output are needed for both research and forecasting purposes (e.g., pattern recognition applied to satellite images).

References

CEDAR Steering Committee. 1986. Coupling, energetics, and dynamics of atmospheric regions "CEDAR," vol. I: overview.

Committee on Earth and Environmental Sciences. 1993. Our changing planet: the FY 1994 U.S. global change research program. Washington, DC: Federal Coordinating Council for Science, Engineering, and Technology, Office of Science and Technology Policy.

GEM Steering Committee. 1988. Geospace environment modeling "GEM."

National Academy of Sciences. 1992. Solar influences on global change: report to the NRC committee on global change research. Washington, DC: NAS.

National Academy of Sciences. 1991. Assessment of programs in solar and space physics 1991. Washington, DC: NAS.

National Academy of Sciences. 1990. Research strategies for the U.S. global change research program. Washington, DC: NAS.

National Academy of Sciences. 1984. Global tropospheric chemistry: a plan for action. Washington, DC: NAS.

University Corporation for Atmospheric Research. 1987. The atmospheric sciences: a vision for 1989-1994. Report of the NSF-UCAR Long-Range Planning Committee. Boulder, CO: UCAR.

7. EARTH SCIENCES

A. Scope of Research

The ***Division of Earth Sciences*** supports research on the full range of geoscience disciplines and is described more fully in the brochure "Earth Sciences Research at the NSF" listed below. Much of this research is limited by the available instrumentation and techniques for sensing and sampling the subsurface parts of the earth and by the need for accurate chemical and physical analysis of rock, mineral, and fluid samples, both in the laboratory and in deep drill holes.

B. Suggested Subtopics

Proposals are solicited in each of the earth science research programs. NSF would be especially interested, however, in the development of new, improved, or less expensive instruments or techniques for the following research areas:

a. Crustal Studies—Exploring the composition and structure of the earth's crust.

b. Analytical Measurements—Chemical, isotopic, or microstructural analysis of rocks and minerals.

c. Field Measurements—Measurements of the earth's gravitational or magnetic fields.

d. Stress/Strain Measurements—Monitoring of stress or strain in the earth's crust, including borehole and modern geodetic measurements.

e. Seismological Measurements—Measurements of ground displacements or accelerations due to earthquakes and/or man-made sources.

f. Synthetic Materials—Laboratory synthesis of geological materials.

g. Physical Properties—Laboratory measurement of the physical properties of rocks and minerals at high temperatures and high pressures.

h. Deep Drilling and Logging Technology—Coring, fluid sampling, and measurement of physical and chemical properties at depths up to 15 kilometers.

References

IRIS Consortium. January 1993. A national program for research in continental dynamics. CD/2020. Arlington, VA: The IRIS Consortium. [The IRIS Consortium, 1616 N. Ft. Meyer Drive, Suite 1050, Arlington, VA 22209-3109.]

National Academy of Sciences. 1993. The national geomagnetic initiative. Washington, DC: NAS.

National Academy of Sciences. 1993. Solid-earth sciences and society. Washington, DC: NAS.

National Academy of Sciences. 1991. International global network of fiducial stations. Washington, DC: NAS.

National Academy of Sciences. 1990. Facilities for earth materials research. Washington, DC: NAS.

National Science Foundation. 1993. Earth sciences research at the NSF. NSF 93-66. Washington, DC: NSF.

8. OCEAN SCIENCES

A. Scope of Research

The ***Ocean Sciences Division*** supports research to improve understanding of the sea, including the seafloor and the organisms in it, and its relationship to human activities. This research seeks to improve our understanding of the factors controlling physical, chemical, geological, and biological processes in the ocean and at its boundaries (the air-sea interface, the seafloor, and the coastline). These processes control the nature and distribution of marine life, the composition and movement of ocean water, and the character of the ocean bottom.

B. Suggested Subtopics

Appropriate subtopics for SBIR proposals are included in the general range of research supported by the Ocean Sciences Division in the following program areas: Marine Geology and Geophysics, Chemical Oceanography, Biological Oceanography, Physical Oceanography, Scientific Ocean Drilling, and Oceanographic Technology. Areas of specific interest for SBIR support include but are not limited to the following:

a. Oceanographic Measurement, Sampling, and Reporting Systems—

- Integrated measurement and reporting systems for unattended deployment on buoys and/or moorings that provide high-frequency, real-time chemical, biological, and physical data to support investigation of biologically important elements.

- Underway sampling techniques for physical, biological, or chemical parameters.

- Stable sensors for long-term measurement (1, 2, or more years) of physical, chemical, and biological parameters.

- Discrete nutrient measurement systems.

- Biological sampling equipment and automated analysis systems.

- Vertical profiling systems.

- Remote sensing of the ocean environment using acoustic, optical, or electromagnetic techniques.

- Systems for rapid and wide-scale measurements using satellite, airborne, or other remote techniques.

- Reliable sampling systems for the recovery and quantification of seafloor samples, particularly hard consolidated rock samples using standard oceanographic ships as the deployment platform.

- Coring, sampling, and logging tools and techniques for use in scientific ocean drilling utilizing floating drilling platforms. Systems for drilling and sample recovery in hard, often fractured oceanic crust. Devices for recovery of pressurized cores. Measurement while drilling techniques. High-temperature drilling, coring, and logging systems. Adaptation of mining drilling techniques for offshore use to drill in hard rock.

- Simplified techniques for assembling, managing, archiving, and disseminating large, diverse oceanographic data bases.

b. Marine/Estuarine Aquaculture—Research proposals are requested that are directed toward improving cultivation practices for marine organisms. Selected species or processes should have a clear-cut commercial potential and the need for further acquisition of scientific data to illustrate their value or utility. Areas of emphasis include the following:

- Application to Biological Research—culture of organisms for use in scientific laboratories, biotechnology research, and for stock enhancement purposes.

- Application to Food Production—new approaches to increase production efficiency, e.g., genetic improvements, reproductive biology, disease control, and polyculture systems.

Reference

National Science Foundation Advisory Committee on Ocean Sciences. August 1987. A unified plan for ocean science: a long-range plan for the ocean sciences of the National Science Foundation. Washington, DC: NSF.

9. POLAR SCIENCE, ENGINEERING, AND OPERATIONS

A. Scope of Research

The *Office of Polar Programs* supports research to promote new discovery and knowledge of the Arctic and Antarctic. These are regions of extreme cold and of long periods of light and darkness; they consist predominantly of snow, land and sea ice, and frozen ground. The principal research interests are to understand and predict physical, chemical, and biological properties and processes of materials and organisms at low or subfreezing temperatures and to understand their relationships to human activities.

B. Suggested Subtopics

The following subtopics for polar and related cold regions of the earth are appropriate for SBIR support.

a. Engineering Research for Operations and Construction—Research is required on new ideas and improved methods of operations and construction at low temperatures and in wind-dominated environments. Adaptation of knowledge developed in the Arctic and other northern regions for Antarctic conditions is of particular interest. Areas of interest include but are not limited to the following:

- Construction techniques for permanent and temporary structures, including expeditionary camps.
- Transportation systems in cold environments including roads, bridges, foundations, pipelines, and airfields.
- Energy recovery systems, in particular for conditioned air inside buildings, that include effective removal of indoor air contaminants.
- Fire suppression systems for structures located in environments where water can be as damaging as the fire and typical chemical suppression systems may be hazardous to occupant health or to the environment.

b. Communications—Applications of modern digital communications systems are important. Areas of interest include but are not limited to the following:

- Low-cost, portable communications systems adaptable to the polar field environment.
- Research and development of techniques for the implementation of telescience (remote interrogation for command, control, and data transfer) between experimental apparatus located in the polar regions and a researcher located in the United States.

c. Navigation—Improved navigation systems to locate and navigate to a remote field party, regardless of most weather conditions, is important for human health and safety. Areas of interest include research on low-cost navigation and positioning receivers suitable for polar field use at ambient temperatures.

d. Alternative Power Systems—Research on alternative power systems that can effectively use *in situ* sources of energy, (e.g., wind and solar radiation) in the polar regions. Areas of interest include the following:

- Integration of high-efficiency conventional power sources and alternative power sources through intelligent power systems management.
- Energy storage systems for application in remote areas.

e. Information Systems—Research on systems to manage polar data and information.

f. Human Factors—Research on adaptive factors for working in hostile, isolated environments; areas of interest include but are not limited to the following:

- Screening and selection of individuals suited for assignments of long duration in relative isolation.
- Factors and equipment for safely extending the endurance and productivity of underwater divers in cold waters.

References

Journal of Cold Regions Engineering. December 1989. Cold regions engineering research—strategic plan. *J. Cold Regions Eng.* 3(4).

National Science Foundation. Spring 1993. Arctic research of the United States. Vol. 7. Arlington, VA: NSF. [National Science Foundation, Arlington, VA 22230.]

Polar Research Board. 1985. National issues and research priorities in the arctic. Washington, DC: National Research Council, 124 pp.

10. INTEGRATIVE BIOLOGY AND NEUROSCIENCE

A. Scope of Research

The ***Division of Integrative Biology and Neuroscience*** supports research in the areas of developmental biology, physiology and behavior, and neuroscience. Its major emphasis is on the integration of molecular, subcellular, and cellular approaches to better understand the development, functioning, and behavior of organisms in both laboratory and natural settings. This research provides answers to questions about how plants and animals grow, reproduce, and function; how life processes are initiated, regulated, controlled, and integrated at the level of the gene, cell, and organism; and how biological and environmental factors underlie animal behavior, with explicit emphasis on nervous system development, structure, and function. The Division does not consider proposals for clinical research or research directed principally toward medical goals.

B. Suggested Subtopics

Examples of current interest in the Division's programs include but are not limited to the following:

a. Commercial Exploitation of Plants and Animals—Creation or use of transgenic plants or animals to produce novel strains or products with potential commercial applications.

b. Biocontrol for Agriculture and the Environment—Cellular and biochemical approaches to controlling biological processes in various life stages of organisms that have economic value (e.g., desiccated seeds, fruit ripening, stress resistance, embryo cryopreservation, biological pesticides and herbicides, and the development and exploitation of aquatic species for aquaculture).

c. Biomaterials and Bioprocessing—Use of, or improvements in, abilities of plants or animals to produce novel, useful products (e.g., adhesives, lubricants, biodegradable polymers, flavors and fragrances, and biosensors). Improvements in biological means of converting animal or plant materials into useful products. Innovations in the use of animals and plants in extracting valuable compounds from ore or wastes.

d. Animal Behavior—Field or laboratory studies involving the behavioral aspects of the breeding and management of endangered and threatened species and the control of pest populations; and studies involving behavioral effects of chemical substances such as hormones, pheromones, pesticides, and environmental toxins.

e. Optical Imaging of the Nervous System—Improved hardware and software for studies of the organization and function of the nervous system using optical imaging techniques. These may be based on but are not restricted to specific molecular probes (calcium or voltage) and activity-dependent changes in intrinsic optical properties of nervous tissue.

f. Molecular Design—Molecular design of neuropeptides and neuronal proteins with the aim of developing nonprotein substitutes that demonstrate activity in the nervous system. This can be accomplished through improved computer-aided models or by other means.

g. Molecular Computing—Studies related to the identification of stable natural or stable synthesized biosensors and voltage sensing devices that could provide the basis for molecular circuit design. Design of computer architectures (e.g., preprocessing, post-processing, central processing, memory-based, and adaptive) to support molecular computing systems.

h. Neuronal Circuitry—Neuronal circuitry research and development of models or databases for neuronal circuitry, pattern generation, and neural networks.

i. Recording and Display Technology—Development of hardware and/or software for handling recordings where high-temporal resolution, multiple inputs, waveform analysis, or other factors require novel solutions. Display technology for industrial and commercial use, including but not restricted to virtual reality systems.

11. MOLECULAR AND CELLULAR BIOSCIENCES

A. Scope of Research

The *Division of Molecular and Cellular Biosciences* supports research aimed at understanding life processes at the molecular and cellular levels using biochemical, biophysical, and genetic approaches. This includes research on aspects of biotechnology; on the structure, function, biosynthesis, and interactions of macromolecules; on intermediary metabolism, chemical conversion and bioproduct formation; on the assembly, function, and organization of cellular components; and on the mechanisms, and the regulation of expression and transmission of heritable information. The Division does not consider proposals for clinical research or research directed principally toward diseases or drug development.

B. Suggested Subtopics

Examples of subtopics of current interest in the programs of the Molecular and Cellular Biosciences Division, particularly in biotechnology and bioremediation, are suggested below.

a. Macromolecular and Technologies—The application of cellular, biochemical, and biophysical techniques to improve the usefulness and availability macromolecules. Areas of interest include but are not limited to the following:

- Identification and characterization of novel enzymes, especially those that operate in organic solvents, and/or under extreme conditions of pH, temperature, pressure, or ionic strength.

- Engineering secretory machinery in cells for export of macromolecules, such as proteins and carbohydrates.

b. Biomolecular Materials—The application of molecular and cellular approaches to characterize and synthesize new biomolecular materials with desirable properties or to enhance the processing of established biomaterials. Areas of interest include but are not limited to the following:

- Development of biosystems for production of fibers, adhesives, and plastic films.

- Preparation and application of biomagnetic materials.

- Development of novel methods for starch and biological wax synthesis.

c. Microbial Biology and Other Environmental Technologies—The application of cellular and molecular approaches to enhance our capacity to make use of microbes for purposes of bioconversion, bioremediaton, or waste management. Areas of interest include but are not limited to the following:

- Development and application of biosensors or other technologies to identify and characterize physiological or chemical reactions, especially those at work in natural microbial communities.

- Engineering microorganisms with improved capacity to degrade xenobiotic compounds, especially halogenated cyclic materials.

- Modification of metabolic pathways in cells to provide novel new biodegradable compounds.

- Identification of biogeochemical cycling processes for bioremediation of heavy metal pollution.

d. Plant Biology—Cellular and molecular approaches to enhancing the understanding of the

mechanisms underlying the function and organization of biological processes in plants. Areas of interest include but are not limited to the following:

- Modification of the lipid composition of oilseeds.

- Improvement in the control of fruit ripening.

- Engineering plants with greater resistance to physical, chemical, and biological stress.

- Transformation of woody plant species to improve their food and fiber production capacity.

e. Genetics—The application of genetic techniques, including the use of recombinant DNA technology, to improve products and to develop new methods for production of economically important materials. Areas of interest include but are not limited to the following:

- Development of genetic techniques for the isolation of catalytic antibodies with properties useful for industrial applications.

- Improvement of techniques for the detection and characterization of minute amounts of DNA.

- Development of techniques for long-term preservation of DNA, plant and animal germ plasm, or organisms.

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Uchida, T. 1988. Introduction of macromolecules into mammalian cells by cell fusion. *Exp. Cell Res.* 178.

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12. ENVIRONMENTAL BIOLOGY

A. Scope of Research

Research in the ***Division of Environmental Biology*** advances the understanding of organisms and their environment. The Ecological Studies programs address functional interactions among plants, animals, fungi, and microorganisms of terrestrial and freshwater systems. The programs in Population Biology and in Systematics support studies of the genetic and evolutionary bases for adaptations in morphology, physiology, and life history that allow organisms to respond to changing environments. SBIR projects in environmental biotechnology offer new approaches to biodiversity and to ecosystem function and contribute to environmental restoration and stewardship.

B. Suggested Subtopics

a. Environmental Analysis/Natural Resources Research—Loss of biological diversity and pollution degradation are major environmental problems. Mitigation strategies for natural and managed ecosystems require knowledge of component organisms and their ecological functions. New molecular techniques to characterize microbial community structure and function promise improved methods for analyzing and monitoring natural and stressed ecosystems. Molecular probes may provide sensitive assays to investigate the response of organisms to environmental changes. Molecular methods provide powerful tools for the measurement of biodiversity, particularly at the genetic, population, and species levels, and for the maintenance of threatened species and communities. Instruments are needed to provide nondestructive measurements of root biomass, activities of soil organisms, and element fluxes in the rhizosphere. Field instruments providing real-time analyses of variables linking the biosphere and lithosphere over spatial scales of meters to kilometers are

needed; trace gases, volatile organics, and isotopic composition are examples of such variables.

b. Biorestoration and Bioremediation—The goals of biorestoration research are to modify desired species to restore their populations and to develop technologies that will restore the overall structure and function of degraded ecosystems. Methods need to be developed to increase the reproductive potential of species for gene pool protection and recovery of endangered and threatened populations. Ecologically sound techniques are needed to restore wetlands, stream ecosystems, and other polluted communities and to mitigate the impacts of exotic introductions. Research in bioremediation is needed to identify organisms capable of metabolizing pollutants, toxic substances, and metals at the site of disturbance. The primary goal of much of the research in bioremediation is the isolation, taxonomic identification, and biochemical characterization of microorganisms capable of carrying out specific chemical transformations.

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13. BIOLOGICAL INSTRUMENTATION AND RESOURCES

A. Scope of Research

The ***Division of Biological Instrumentation and Resources*** supports research that will lead to new instrumentation or software for research applications in the biological sciences. This research includes the development of innovative new technological or methodological approaches, as well as substantial or radical improvements in currently available instrumentation and software to increase performance and/or significantly reduce cost. Proposals directed principally at medical or clinical research topics are not supported.

B. Suggested Subtopics

Proposals are solicited for instrumentation and software development that are appropriate for application in the performance of research or industrial processes in the areas of environmental biology, plant biology, neuroscience, animal behavior, physiology, biochemistry, biophysics, genetics, cell biology, and molecular biology. Special consideration will be given to the development of instrumentation and software that have potential to contribute to research under current NSF areas of interest in the Biological Sciences, including high-performance computing, biomolecular materials, biotechnology, biodiversity, conservation biology, and instrumentation that is innovative and of significantly lower cost.

a. Biological Structure Research Technology—Research leading to new or improved methods for the analysis of biological structure using NMR, x-ray detectors, optical microscopy, and other appropriate tools, including data acquisition software and data capture methods.

b. Computer-Assisted Modeling—Research on more efficient or reliable algorithms and improved data handling and output display methods to assist biological studies ranging from macromolecular structure research to ecosystem modeling.

c. Distributed Databases—Research on the design and development of biological information resources, such as data libraries, theoretical data models, tools for structuring and retrieving biological data, and algorithms and software related to the management and analysis of information resources.

d. Biological Function Research Technology—Research leading to new or improved methods for the analysis of biological function in plant or animal systems, such as remote sensing monitors or tracking systems.

14. SOCIAL, BEHAVIORAL, AND ECONOMIC RESEARCH

A. Scope of Research

The ***Division of Social, Behavioral, and Economic Research*** supports research in a broad range of disciplines and interdisciplinary areas. The goals of the Division are to advance fundamental scientific knowledge about (1) cognitive and psychological capacities of human beings; (2) cultural, social, political, spatial, environmental, and biological factors related to human behavior; (3) human behavior, interaction, and decision making; (4) social, political, legal, and economic systems, organizations, and institutions; and (5) the intellectual, value, process, and impact contexts that govern the development and use of science and technology. Research is supported in the fields of anthropology, decision science, economics, geography, linguistics, management science, operations research, political science, psychology, regional science, sociolegal studies, sociology, and science and technology studies.

B. Suggested Subtopics

Proposals are solicited in all areas of social, behavioral, and economic research in the fields indicated above. **Proposals must conform to standard research protocol in the social, behavioral, and economic sciences. Proposers are encouraged to consult with academic researchers in crafting their research designs. Projects involving a consulting services component as a product will not normally be supported.** Specific subtopics of interest include but are not limited to the following:

a. Anthropological Methods—Improved methods for social impact assessment, studies of the developmental process, and physical anthropology of prosthetics.

b. Archeological Methods—Improved methods of dating including radiocarbon, thermoluminescence, and others (these may include sample preparation as well as measurement); analysis of archaeological materials (both inorganic and organic such as bone and tooth); and remote and on-the-ground archeological site mapping techniques.

c. Decision Analysis, Risk Analysis, and Management Science—Research should have relevance to an operational context, be grounded in theory, and be based on empirical observation or be subject to empirical validation. Some areas of interest include the following:

- Management science models including innovative advances in model development, implementation, and application for planning, scheduling, and control of management operations in the private and public sectors.

- Decision analysis models for individual and group decision making. Emphasis is on new and improved methods to support tools such as software for creatively structuring decision problems and for evaluating alternative actions and on the development or evaluation of theory-based decision aids for individuals or organizations.

- Inferential models including advances in technologies, such as inferential networks, for handling massive amounts of data applications of these methods to novel problems and improvements in methods and applications of probabilistic inference.

- Risk analysis and communications including improved methods for analysis of environmental health and financial risks, enhanced technologies for communicating risk information, and management of low probability-high consequence events, such as siting potentially hazardous facilities and process redesigning for pollution prevention and cost reduction.

d. Economics—Collection of and improved access to economic data; development and dissemination of software for econometric analysis, economic modeling, economic laboratory experiments, and other areas of computational economics; economic forecasting; and research in all other areas of economics such as finance, international economics, labor, and industrial organization.

e. Geographic Information Systems (GIS)— Development and adaptation of GIS for locational decision making and other types of geographical analysis. Possible applications should be well-grounded in scientific understanding of both GIS and the topic for which the analysis will be used. Applications should not be narrowly focused.

f. Cognitive and Social Psychological Research— Research leading to product development in areas such as the following: human factors; organizational psychology; psychometrics; assessment of physiological state; computer-aided instruction; deception detection; processing of facial, vocal, and epressive information; and improved methods/instrumentation for the collection and analysis of observational behavioral data.

g. Law-Related Behaviors and Processes— Improved understanding of the behavior of individuals as well as of groups or organizations as they affect or are affected by legal processes and institutions, including work on criminality; disputing and alternative systems and models of dispute resolution; legal decision making; the interaction of law, science, and technology; and the development of models and methods for improving our understanding of law and other systems of social control and governance in society.

h. Linguistics—Studies of factors involved in second-language learning; studies of perception of synthesized and natural speech; and development of computer-based methods for semantic and syntactic analysis of natural language.

i. Management of Technological Innovation— Studies of the innovation process in industry by teams with social and behavioral science expertise. The aim is to make the innovation process both faster and more efficient. Phase I should proceed as far as testing instruments in industry. Subjects might include software generation, entrepreneurism, decision support systems, etc.

j. Marketing Methodology—Development of general marketing methodology that is based heavily on psychological, economic, sociological, and decision research concepts. Possible project areas include forecasting the impacts of product improvements and/or price changes on sales. ***Specific product market research will not be supported.***

k. Methodological Advances—Improved methods for survey research and the quantitative analyses of social and economic data.

l. Sociology and Human Resources—Technologies to enhance collection and analysis of social data; studies of the ways that individuals and groups function in a variety of contexts, including the following:

- Computer software and related technologies for collecting information about social institutions, structures and processes; techniques for analyzing, reducing, and applying sociological data; systems for distributing raw data and findings from sociological research studies.

- Sociology of work including studies of the effects of new technologies on the organization of work; small-firm ownership and the economic integration of new immigrants; organizational form and firm success; and determinants of entrepreneurship. Development of models for analyzing the effects of work environments on worker satisfaction and productivity.

m. Studies in Science, Technology, and Society— Studies of processes of research and technological innovation, particularly what factors lead to success or failure and what the impacts are and studies of ethics activities in science and engineering corporations, laboratories, and classrooms. (See current NSF Studies in Science, Technology, and Society Program Announcement.)

15. ADVANCED SCIENTIFIC COMPUTING

A. Scope of Research

Emerging high-performance computing (HPC) environments for large-scale scientific and engineering computations will have many components including high-performance vector computers, shared memory multiprocessors, distributed memory multiprocessors,

special-purpose hardware, graphic engines for visualization, peripheral mass-storage systems, and hardware performance monitors.

The New Technologies Program supports research related to the use and the removal of barriers to the use of such environments in solving large-scale scientific and engineering problems. To make effective use of such environments requires the creation of software and tools with wide applicability. Software and tools limited to a specific application are not acceptable in this context.

B. Suggested Subtopics

Proposed projects must have well-defined research goals with new research issues clearly identified. Novelty of approach and development of new methodologies must be stressed. In all cases, **the relationship to high performance computing and the impact of the research on large scale scientific and engineering applications must be made explicit in the proposal.** In addition, the wider the applicability, the more appropriate the research. It is not sufficient to simply utilize a high performance computing environment in the research.

a. Scientific and Engineering Applications—The availability of massively parallel and other high-performance computers is impacting the research of scientists and engineers with large-scale applications. Efficient utilization of such computers requires research involving

- New algorithms.
- New and more powerful numerical methods.
- New data structures.
- Conceptual models of scientific computations.
- Improved visualization techniques.
- Techniques for dynamic load balancing.

b. Scientific and Engineering Software for High Performance Computers—User-friendly software must be developed for effective use of emerging high performance computing environments. Research areas of interest are the following:

- Preprocessors for extracting parallelism.
- New constructs for expressing parallelism.
- Languages and compilers for parallel processing.
- Parallel debuggers.
- Coordination languages for heterogeneous sys tems.
- Visualization software.
- Improved operating systems.
- Methods of evaluating performance of HPC systems.
- Techniques for dynamic load balancing.

c. Innovative Support Systems—High-performance computing systems frequently entail support requirements unique to their environments. Research supporting the development and use of such systems is needed. Areas of interest include the following:

- Mass-storage systems for parallel architectures.
- Visualization support systems.
- Hardware-monitoring systems.
- Network architectures for heterogenous systems.

16. COMPUTER AND COMPUTATION RESEARCH

A. Scope of Research

Computer and computation research discovers the fundamental scientific and engineering laws that govern the design, manufacture, and use of computing systems. This research ranges from mathematical studies of

problem-solving procedures to engineering studies of new, advanced computing systems that test and utilize the laws. Subjects for study include the following:

- Strategies and algorithms for solving problems, including methods of representing and transforming information.

- Programs and software systems for solving large problems or controlling complex systems.

- Machines for executing programs.

Much of the research is aimed at order-of-magnitude improvements in capabilities of computing systems that cannot be obtained by incremental improvements in the underlying electronics.

Parallel and distributed computation has been a basic theme for much of the research supported. Promising new parallel and distributed architectures are key technologies for future advances in high-performance computing. Further progress toward effective high-performance computing requires newer algorithms, languages, tools, and software systems. To develop these technologies, new research is required in theory, problem solving, design, and implementation.

Research on complex software systems is also of current national importance, since software is frequently cited as the major factor determining the high cost and unreliability of critical, complex, computer-based systems. Fundamental issues in this area include new methods of engineering safe, secure, failure-free, software systems, advanced techniques for reducing the cost of software development, and new technologies to make programming and using computers less costly and less prone to error.

B. Suggested Subtopics

Research should focus on techniques and mechanisms that will increase the utility of computers and their application to commercial problems. Only proposals for development of original concepts in which scientific knowledge is applied to one of the areas listed below will be considered under Topic 16. Moreover, a proposal must clearly specify the innovative concept or technique for which feasibility is to be determined, the scientific issues to be investigated, and the proposed research plan. A statement of need and potential benefits is not sufficient.

Investigators should avoid producing tools that are widely available (e.g., screen editors). In addition, implementations of large, complex, software systems are unlikely to succeed within the time frame of the SBIR program.

a. Software Engineering—Research in this area should concentrate on methodologies and tools for the development, maintenance, and management of sequential, parallel, distributed, or real-time software systems. Areas of interest are the following:

- Software prototyping.

- Software specification design and reuse.

- Software validation and verification.

- Software measurement and process.

- Software development environments.

b. Operating Systems and Systems Software—Research in this area deals with operating systems, systems tools, and libraries for all levels of computers and networked resources, with emphasis on systems software for high-performance environments. Areas of interest are the following:

- Operating systems.

- Software tools for systems programming.

- Communication and cooperation of researchers in parallel and distributed computers.

- Systems resource management.

- Systems security.

c. Computer Systems Architecture—Research is needed on the design, evaluation, analysis, and development of computer architectures and related

algorithms and software systems. Research focus is needed on computer architectures at a high level of abstraction and their supporting theory, models, software, and algorithms. Areas of interest include the following:

- Tools for performance evaluation.
- Fault-tolerance and reliability.
- Caches and memory management.
- Parallel architecture.
- Special-purpose architecture.
- Simulation and modeling techniques.

d. Numeric, Symbolic, and Geometric Computation—Innovative research is needed on algorithms, techniques, systems, and tools for symbolic and algebraic computations. Other needs include computationally-oriented numerical analysis, numeric-symbolic interfaces, visualization of scientific computations, scientific and engineering applications based on symbolic computing techniques, and development of parallel algorithms for numeric, symbolic, and geometric computations. Areas of interest include the following:

- Computer algebra systems.
- Scientific and engineering applications.
- Packages for mathematical programming and optimization.
- Modeling in geometric computation.
- Tools and environments for scientific computation, including numerical, symbolic, and geometric techniques.

e. Computer Graphics—This aspect of the program includes research in the computer science issues in computer graphics. Areas of interest include the following:

- Algorithms and data structures.
- New input and display methods.
- Image synthesis.
- Geometric modeling of physical objects.
- Representation of curves and surfaces.
- Computer animation.

f. Programming Languages and Compilers—This area deals with all aspects of programming language research and compiler development. The area seeks to further the integration of programming language research with advances in high performance computing. Areas of interest include the following:

- Compilers and computation techniques.
- Compiler-based tools.
- Special-purpose language.
- Languages and compilers for parallel computers.
- Languages and compilers for object-oriented, functional, and logic programming.

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17. NETWORKING AND COMMUNICATIONS RESEARCH AND INFRASTRUCTURE

A. Scope of Research

The Networking and Communications Research Program of the *Division of Networking and Communications Research and Infrastructure* supports research in communication and information theory and systems, including their treatment in the context of communication networks. Special emphases include optical networks; networks integrating voice, data, and video; multimedia networks, wireless networks and wireless access to networks; and representation, transmission, storage and retrieval of data, voice, image, and video information. High-definition video systems, cellular radio systems, packet radio systems, satellite communications systems, high capacity storage systems, and very high speed networks are examples of information technology applications areas.

B. Suggested Subtopics

Examples of research topics include but are not limited to the following:

a. **Network Architectures**—Modeling, analysis, and design of network architectures and topologies.

b. **Network Protocols**—Protocol development including fast computation protocols for very high speed networks, formal models for protocol development, distributed protocols, and protocol specification, verification, and performance.

c. **Network Management**—Routing, flow control, performance modeling and analysis, fault diagnosis, and distributed algorithms.

d. **Optical Networks**—New architectures especially designed for optical networks, performance comparisons among alternative, new architectures, and new approaches to high-speed switching and switch design.

e. **Multimedia Networks**—Techniques, protocols, algorithms, and architectures for the creation, transmission, storage and retrieval, sharing of multimedia information.

f. **Data Compression**—Source coding, scalar and vector quantization, pattern recognition, transform coding, and nonstationary source statistics, with applications to communications and networks.

g. **Image Processing**—Representation and coding of image information for storage, retrieval, transmission, and sharing in network environments.

h. **Modulation and Coding**—Coding and modulation for efficient and reliable transmission and storage of information, particularly in very high speed electronic or optical systems, in wireless access systems, for fading and dispersive channels, and for very high capacity storage systems.

i. **Communications Signal Processing**—Detection, estimation, acquisition, and tracking of signal parameters; nonlinear receivers, non-Gaussian additive or multiplicative channel noise or interference, random or time-varying channel transmission parameters, adaptive signal processing, and algorithms and architectures for implementation.

j. **Network and Communication Security**—Encryption/decryption algorithms, efficient hardware implementation, key generation and distribution, m-ary security systems, and security management systems.

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National Science Foundation. April 9-11, 1992. Research priorities in networking and communications. NSF 92-109. [Available on-line through STIS.] Washington, DC: NSF.

18. MICROELECTRONIC INFORMATION PROCESSING SYSTEMS (MIPS)

A. Scope of Research

The advent of gigabit networks, high-performance microprocessors, and parallel systems is dramatically impacting research on systems-level architecture of high-performance computing systems. The area of computing systems that involves the structure of computers is central to the ***Division of Microelectronic Information Processing Systems*** today and will be even more so in the future. This is a core area of computer science and engineering, and in the 1990's it encompasses much more than just hardware. Computing systems deals with computer architecture, hardware implementation, system software (operating systems and compilers), networking, and data storage systems.

The emphasis in MIPS is on real systems, both analog and digital. Special weight is placed on design, prototyping, evaluation, and novel use of computing systems and on the tools needed to design and build them. This involves technology-driven and application-related research, experimental research, and theoretical studies. The MIPS programs support research in the following areas: high-level design (design automation and CAD tools); systems-level architecture studies; experimental systems research projects that build and evaluate hardware/software systems; signal processing algorithms and systems; knowledge of applications; methodologies, tools, and packaging technologies for rapid prototyping at the SYSTEM level; and infrastructure needed to support MIPS educational and research activities. **Research on device physics and the fabrication process is not supported by MIPS.**

B. Suggested Subtopics

Central research issues are managing the complexity of design, creating new functional capabilities, and developing application specific computers. A major goal of the Division's research is producing the knowledge and mechanisms permitting the economical and simplified creation of new and special purpose information processing and computing devices.

Only proposals for development of original concepts in which scientific knowledge is applied to one of the areas listed below will be considered under Topic 18. Moreover, a proposal must clearly describe the innovative concept or technique for which feasibility is to be determined, the scientific issues to be investigated, and the proposed research plan. A statement of need and potential benefits is not sufficient.

a. Design, Tools, and Test—Research is directed at obtaining fundamental knowledge about the complete design cycle for integrated circuits (IC's) and systems from conception through manufacturing and operational test. Emphasis is on automating the design and testing processes. Because advances in technology make it possible to design a system on one or a few chips, however, the design process has become far more complex. The higher operating and switching speeds make electrical effects more pronounced, thus causing a new dimension in electronic design automation (EDA) design. These drivers dictate the major research problems: (1) how to rapidly design a complex IC system; (2) how to verify the resulting design; and (3) how to test the manufactured product. The four research areas are as follows: Theoretical Foundations, Design Automation and Tools, Manufacturing Test, and Design Simulation. Activities of interest are the following:

- Verification and proof of correctness of designs.
- Algorithms and tools for synthesis and optimization.
- Physical design of high-speed circuits and systems.
- Logic and higher level design.

- Mixed-signal (analog—digital) circuit design tools.

- Simulation at different levels.

- Parallel algorithms for VLSI design tools.

- Algorithms for testing sequential circuits based on realistic faults.

- Efficient test pattern generation for sequential circuits.

- Fault diagnosis and error detection.

b. Microelectronic Systems Architecture— Research is on computing systems and methods for their design, with emphasis on physically realizable systems. Particular interest is on designs of new computer systems architectures brought about by the impact of either new technologies or new applications or both. Technologies include the following: VLSI, ULSI, wafer-scale integration, optoelectronic and optical interconnect, multichip modules, and field programmable arrays. Applications include scientific computing, graphics, manufacturing, education, digital signal processing, communications, neuro-computing, symbolic processing, and knowledge and data engineering. Subjects of interest are as follows:

- Designs and methodologies for innovative microsystems at the physical chip level (chip, wafer and multichip), as well as at the abstract conceptual level that can better utilize emerging technologies to achieve more efficient architectures.

- Special purpose computing systems for applications whose computational requirements cannot be met by conventional architectures in the foreseeable future.

- Innovative parallel architectures.

- Fault tolerant systems.

- Memory system architectures.

- I/O system architectures.

c. Circuits and Signal Processing (CSP)— Research is in the areas of digital signal processing (DSP), analog signal processing, and supporting hardware and software systems. A classification of the CSP Program based on signal characteristics, applications, and technology is as follows: One-Dimensional (1-D) DSP—representation of 1-D signals in digital form and subsequent processing of such signals; Multi-Dimensional DSP—signals which are inherently functions of two or more independent variables; Circuits—concerned with the better understanding of nonlinear and high-frequency circuits; VLSI signal processing—algorithms and architectures that can be mapped onto VLSI circuits. Areas of interest include the following:

- New approaches to nonlinear signal processing, new orthogonal decompositions and representations, and new filter structures and designs—biomedical applications, image and speech coding, video, and communications applications such as active noise control, etc.

- Image/signal compression, reconstruction, and/or enhancement—applications to HDTV and digital video imaging (DVI).

- Novel applications of signal processing algorithms, e.g., applications of array processing to manufacturing.

- Implementations in analog, digital, mixed analog/digital, and optical technologies.

[Note: The SBIR programs of the DoD have a strong component in signal processing that addresses defense applications; proposals involving such problems are ineligible at NSF.] SBIR proposals containing innovative research ideas for possible commercial applications are strongly encouraged.

d. Systems Prototyping and Fabrication— Research is on technologies, tools, and methodologies needed for the prototyping of information processing systems for experimental use. Emphasis is on issues that arise in creating, in a timely way, prototypes of systems and on automating the microchip fabrication process. In

systems prototyping, ways are sought to rapidly prototype systems of chips and boards that can provide realistic and timely feedback for overall system design. In automating the microchip fabrication process, ideas on modeling, simulating, measuring, automating, and improving the fabrication are sought.

Areas of interest include the following:

- Board-level design frames.
- Experimentation with new system interfaces.
- Development of new prototyping techniques and services.
- Use of new packaging techniques, such as multichip modules.
- Tools to aid in the rapid prototyping of systems, e.g., simulation, layout, and intelligent aids to design.
- Tools to promote automation of the microchip fabrication process, e.g., tools to model, simulate, measure, and control the fabrication system.
- Interconnect tools.

Research on device physics and the fabrication process is not supported here. ***[Note: Topic 20.a covers research in these areas.]***

e. Microelectronics Education—Support here includes development of curriculum and course materials and of educational support services, such as field programmable gate arrays (FPGA's). Areas of interest are the following:

- Development of cost-effective teaching materials.
- Tools for lab use, such as system building kits that permit experimentation with FPGA's, multichip modules, etc.

f. Experimental Systems—Projects supported involve building and evaluating information processing and computing systems. These are goal-oriented projects, usually undertaken by teams of designers, builders, and users. Emphasis is on the building of the system and on research experiments involving the system that address significant and timely research questions. The building of the system itself must represent a major intellectual effort that offers advances in understanding of information processing systems architecture. System prototypes that are built should be suitable for exploring applications and performance issues.

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* Available from the MIPS Division Office.

19. INFORMATION, ROBOTICS, AND INTELLIGENT SYSTEMS

A. Scope of Research

Research in the ***Information, Robotics and Intelligent Systems Division*** seeks to increase scientific knowledge of information processes in machines and complex systems. Central to the understanding of these processes are the properties of symbolically interpreted representations and the dynamics of their propagation and aggregation.

B. Suggested Subtopics

Four problem areas of special interest are database and knowledge base systems, formal knowledge representations and processing methods in intelligent systems, robotics and intelligent perception, and user-system interfaces in interactive systems. Only proposals describing original research in which scientific knowledge of information processes is applied to one of these problems will be considered under this topic. **A proposal must clearly specify the innovative concept or technique for which feasibility is to be determined, the proposed scientific issue(s) to be investigated, and the proposed investigative procedure. A statement of need and potential benefits is not sufficient for this purpose.**

For subtopics (a) and (b), below, proposals simply to implement database or knowledge base systems for a given application will not be considered. For example, traditional expert system or database design and implementation applied to specific domains is inappropriate.

a. Database and Knowledge Base Systems—These areas of research include methodologies and tools for innovative database and knowledge base design, implementation, management, and use. Areas of interest for SBIR proposals are the following:

- Heterogeneous/distributed databases.
- Multimedia databases.
- Object-oriented databases.
- User-friendly design and query languages.
- Database/knowledge base validation tools.
- Full text processing.

b. Knowledge Representation and Processing—Research is encouraged on innovative ideas in artificial intelligence and machine learning. Areas of interest for SBIR proposals are the following:

- Hybrid symbolic and highly parallel processing.
- Human cognitive modeling.
- Time-critical intelligent systems.
- Machine learning.
- Intelligent systems in dynamic and uncertain environments.

c. Robotics and Intelligent Perception—Intelligent machines perceive their environment and respond by planning and executing complex tasks to accomplish high-level goals. Research is encouraged on representations and algorithms that can acquire, analyze, and interpret sensory data in a timely way and control the action of robots and machines operating in structured or unstructured environments. Specific research problems include the following:

- Symbolic interpretation of 2-D or 3-D images.
- Visual and tactile perception, fusion of multisource sensory data, active sensing, object recognition, and visual inspection.
- Reasoning with incomplete sensory evidence and real-time spatial and temporal reasoning.
- Task and motion planning, sensor-based dexterous manipulation, and hierarchical, distributed, or adaptive intelligent control.

- Motion planning and control of innovative mechanisms for robotic manipulation or locomotion.

Although the proposed research may involve neural networks, the use of a neural-network algorithm in a specific application is not in itself evidence of scientific merit or innovation.

d. User-System Interfaces—Effective human-computer interaction depends on ease of use, suitability for the task, and the scope of functionality. There is a need for research on new ways of interacting with the computer, including new and alternative input/output device technologies, systems that use intelligent interface agents, advances in real-time operating systems to support dynamic human-computer interaction, and development of interaction evaluation hardware, software, and assessment methodologies. Possibilities include but are not limited to the following:

- Systems and algorithms for input or output by voice, natural language, touch, lip reading, and tracking of gesture, gaze, facial expression, and physiological signals during human computer interaction.

- Interactive (multimedia and multimodal) manipulation of data and the interface system itself.

- Intelligent video and audio analysis systems with advanced capabilities for analysis of interaction sessions to extract information about user behavior and system behavior during the interaction.

- Intelligent interface agents designed to support user value clarification, user goal development, requirements definition, and automatic environ ment production.

- Output techniques for visual display using large flat panels, visualization schemes, 3-D or holographic displays, head-mounted displays, stereo vision systems, stereo audition systems, touch and force feedback systems, and other feedback methods.

To be considered under the (d) subtopic, a proposal must address both the relevant behavioral science and technology research aspects of interaction with and interfacing to humans. A system design without some behavioral evidence to support its key features will not be considered.

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20. ELECTRICAL AND COMMUNICATIONS SYSTEMS

A. Scope of Research

The ***Division of Electrical and Communications Systems*** supports fundamental engineering research to enhance the knowledge base for electrical, electronic and photonic, electromechanical, and optical technologies and to facilitate the integration of these technologies into engineering education. The Division also funds research on analytical tools and techniques for computational simulation and control of complex engineering systems. Specific areas of research supported by this Division include the following:

1. Solid-State and Microstructures—Electronic, magnetic and microelectromechanical device research and research on associated fabrication technologies. Theoretical and/or experimental research efforts support investigations of advanced electronic materials, including compound semiconductors, dielectrics, superconducting and magnetic materials, and applications of these materials in novel device structures. Technologies critical in the fabrication of these structures, such as advanced lithography, *in situ* process sensing/control, advanced processes, and characterization techniques are also supported.

2. Engineering Systems—Analytical and computational methods for the modeling, analysis, estimation, identification, optimization, and control of engineering systems with emphasis on generic methods, including neural network designs, motivated by engineering systems such as manufacturing and production systems, electronic systems, robots, and electric power generation, transmission, and distribution systems. Issues of largeness, nonlinearities, and other complexities are of particular interest.

3. Quantum Electronics, Waves, and Beams—Quantum electronics, lightwave technology or photonics, plasmas, and electromagnetics. Theoretical and experimental studies related to the generation, propagation, interaction, manipulation, and analysis of electromagnetic radiation and charged particles; and to their technological implementation.

4. Communications and Computational Systems—Computational methods, with a focus on algorithms for massively parallel architectures, including the modeling and optimization of engineering systems. Emphasis is on the modeling of complex and interactive phenomena such as electrical, mechanical, and thermodynamic effects in electronic microcircuits. Optical communications systems supports research necessary for the realization of intelligent, high-capacity telecommunication networks, based on a fiber-optic infrastructure.

B. Suggested Subtopics

a. Solid-State and Microstructures (SSM)—The SSM Program supports research efforts applicable to electronic devices, including materials development, materials deposition and processing techniques, physics of device operation, device fabrication, and device demonstration.

Research areas include the following:

- Electronic materials growth and characterization, including growth and characterization of electronic materials, with emphasis on those techniques with future impact for electronic and optoelectronic devices and integrated circuits, as well as techniques that permit electrical characterization of materials. This area has commercial applications such as equipment for characterization and material growth.

- Device processing techniques, such as advanced processing techniques that permit fabrication of improved and novel solid-state electronic devices, with emphasis on fundamental studies of processes that have promise in device fabrication and novel techniques with large potential impact. New resists, transient processing equipment, and advanced sensor systems are examples of commercial applications of research in this area.

- Device physics research, including compound semiconductor devices, novel superconducting devices, and magnetic devices. Experimentally based research, especially investigations into the fundamental physical phenomenon underlying device operation. Emphasis is also on new

device concepts made feasible by small feature size, precise depth control, or innovative processing techniques.

- Device and processing modeling and simulation such as quantitative modeling that relates devices and processing input parameters to output parameters, for use in characterizing both process and device parameters and in simulating electron transport mechanisms in compound semiconductor devices. Also, the mathematical bases of process parameter sensitivity and process and device operation instabilities.

- Microelectromechanical devices. Research is supported on the analysis, design, fabrication, operation, and modeling of microelectromechanical devices. These devices include but are not limited to mechanical and electromechanical sensors, gears, turbines, linkages, valves, pumps, and motors fabricated lithographically. *In situ* medical monitors and microanalytic systems are examples of commercial applications of research in this area.

b. Engineering Systems—The Engineering Systems Program supports basic research in analytical and computational methods for the analysis, modeling, optimization, and control of dynamic systems. Subjects range from introduction of new mathematical methods to implementation-oriented algorithmic research and artificial neural networks. The modeling, estimation, analysis, optimization, and control of systems require more sophisticated tools to address the complexities of future engineering systems.

Research areas include the following:

- Modeling and system identification, including methods to combine first-principle models with experimental data. Characterization of uncertainties in the model parameters and high-frequency dynamics. Estimation, filtering, and decision theory for fault detection and intelligent control. Theoretical and experimental research includes numerically reliable computations and mapping algorithms to parallel architectures for real-time estimation and control.

- Controller design and implementation, including multivariable control of dynamic systems with modeling uncertainties and/or stochastic inputs. Analysis, design, and optimization of nonlinear dynamic systems. The methodology ranges from geometric-algebraic theory to computer-oriented control algorithms. Emphasis is on optimal gain scheduling algorithms, autotuning, adaptive and nonlinear control, fuzzy control, and discrete-event dynamic systems.

- Neuroengineering, which includes problems associated with the design of artificial neural networks to control actions over time or to identify dynamic systems (manufacturing process control, robotics, communication networks, vehicles, etc.). Work on improved supervised learning through hybrid global/local network design or improved real-time convergence is supported. The research must use or develop learning algorithms of general scope and of relevance to large-scale nonlinear problems.

- Power system operation, including theoretical and computational issues associated with state estimation, unit commitment, optimal power flow, automatic generation control, forecasting, power quality, interchange transaction, energy storage, and distribution automation. Emphasis is on the basic challenges introduced by the complexity and expanded use of the interconnected system. This includes research into the impact of advanced technologies such as superconductivity, power electronics, electric vehicles, and wind power systems.

- Security analysis, including fundamental issues of power system loadability, fault analysis, stability, contingency analysis, and reliability. Emphasis is on developing a firm understanding of the theory and algorithms needed to ensure the integrity of the nation's electric power infrastructure. Also included is research into the use of high performance computing and neuroengineering concepts to provide rapid diagnosis of system problems and evaluation of alternative control actions.

c. Quantum Electronics, Waves, and Beams (QEWB)—The QEWB Program supports fundamental scientific and engineering research principally in areas of quantum electronics, including lightwave technology or photonics, plasmas, and electromagnetics. Theoretical and experimental research related to the generation, propagation, interaction, manipulation, and analysis of electromagnetic radiation and charged particles and to their technological implementation is appropriate to this program.

Research areas include the following:

- Quantum electronics, including modern optical and laser-related research, especially coherent optical sources and associated devices and techniques. New laser sources and concepts, novel laser applications, ultra-short pulse phenomena, coherent phenomena, and nonlinear optics research, with emphasis on new materials approaches.

- Lightwave technology, which includes applications of photonics to optical information technology, optical computing, storage, and signal processing. Emphasis is on devices, phenomena, related materials technology, and exploitation of nonlinear properties of matter, waveguide technology, optoelectronic devices, integrated optics, optical switching devices, ultra-fast optical processes, and optical interconnections. Collaboration of materials special lists, chemists, etc., and involvement with other NSF and government-supported programs (e.g., Engineering Research Centers) is encouraged.

- Plasmas, including basic plasma studies and innovative engineering applications in areas other than fusion or space-related research. Emphasis is on development of basic concepts and techniques in the generation and control of plasmas and plasma phenomena. Wave interactions in plasmas, nonlinear phenomena, laser-plasma interactions, and applications of plasmas in technologically important areas such as in semiconductor materials processing. Electron or ion beam generation and utilization.

- Electromagnetics, such as novel applications of electromagnetics theory or advanced electromagnetics device work. Emphasis is on creativity in approach as well as on advancement of the field. Fundamental new research approaches to microelectronics and millimeter wave fields, propagation on a chip in two- and three-dimensional space, radiation and scattering effects, superconducting applications, and high-speed interconnections.

- Remote sensing, including optical, millimeter, and microwave techniques for interrogation and propagation through lossy and complex media and processing of remotely sensed data for interpretation and decision-making support. Emphasis is placed on technologies that will contribute solutions to environmental problems, such as global warming, and aid in the development of mitigation strategies.

d. Communications and Computational Systems—This Program is comprised of optical communications systems and computational engineering. Optical communications systems supports research necessary for the realization of intelligent, high-capacity telecommunication networks, based on a fiber-optic infrastructure. Computational engineering provides the interface between engineering and applied mathematics and integrates computational power with advanced analysis and experiments for engineering applications.

Research areas include the following:

- Optical communications systems supports communication systems research employing optical fiber as the principal medium of transport. Research and development efforts might include but would not be limited to all-optical switching components and systems, high-speed electronic switching components and systems, analog and digital processing techniques pertinent to gigabit telecommunication networks, novel architectures compatible with high-capacity, high-connectivity communication networks, network-compatible low-power personal communication components and subsystems. Materials and device research conducted as part of the QWEB and SSM

programs are coupled closely with this research area.

- Computational engineering supports activities of the discovery, development, and application of computer-oriented algorithms including numerical, symbolic, and other methods of solution for engineering applications. The major areas of support are development of data interpretation techniques (preprocessing and postprocessing of data, multidimensional solution representation, interactive graphics), and development of algorithms (adaptive method, error analysis, concurrent techniques, semi-analytical solutions).

21. DESIGN, MANUFACTURE, AND INDUSTRIAL INNOVATION

A. Scope of Research

The ***Division of Design, Manufacture, and Industrial Innovation*** supports research in the processes, machinery, and systems of modern manufacturing, with the goal of making the country's manufacturing base more competitive through innovation and responsiveness to changing needs. The approach is to create, develop, and expand the scientific and engineering foundations of processing methods for current and future engineering materials and of design and manufacturing methods and systems for making useful products from these materials. The Division supports a blend of experimental, analytical, and computational efforts directed toward economically competitive and environmentally compatible technologies.

Included are methodologies for concurrent design of materials, processing, and manufacturing methods for products with engineered microstructures and properties, devices using innovative fabrication and assembly procedures, and systems that integrate various unit processes. Manufacturing machine, sensor, and computer control technologies for manufacturing processes and operations are of interest, as are operations research and production systems method-ologies that underlie the full range of engineering systems. Integration engineering addresses a complete manufacturing enterprise and its infrastructural components.

B. Suggested Subtopics

Proposals should show a clear commercial application of the research to the current or prospective industrial manufacturing environment. This is not to exclude proposals of a theoretical or speculative nature, but they must exhibit strong commercial relevance. Proposals may be submitted on any subject within the scope of the Division. Subtopics of particular interest include but are not limited to the following:

a. Design—Many critical economic problems can be traced to issues related to the design of products for quality, performance, and cost. New knowledge about theories and methodologies of design is needed, and new applications of current computer technologies can also greatly assist designers. Specific areas include the following:

- Design for manufacturing and the life cycle, including research on human and computer systems that optimize the performance/cost of a product over its entire life cycle, including such issues as manufacturability, reliability, serviceability, and disposability.

- Design environments, including research on design language and geometric representations that enable one to design with features, to design at multiple levels of abstraction, and to edit and analyze in multiple functional views.

- Complex design systems, including research on management and communication in large, complex design projects. Simultaneous or concurrent design experiments.

b. Rapid Prototyping—The ability to prototype a design rapidly reduces the lead time to bring a new product to market. To do so efficiently, prototyping "electronically" with novel information technologies may be a means. To ensure effectiveness, simultaneous consideration of phases in the product life-cycle should be taken. Examples include the following: the synthesis of shape and geometry from engineering analysis, the

association of processes to features, the transformation from design geometry to manufacturing procedures, and methods for physical realization of electronics models.

c. Advanced Manufacturing Processes—Generic research toward advanced processing technologies and new processes for difficult-to-manufacture materials. The goal is to reduce costs and improve productivity, quality, performance, and reliability of manufactured products. The scope includes processing bulk materials into engineering materials (primary processing) and processing engineering materials into discrete parts (secondary processing). Increasing productivity means reducing the lead time between design and manufacture (leading to simultaneous engineering), raising production rates, reducing costs, and improving product quality and reliability while meeting product safety requirements both during manufacture and in service.

- Major advances in conventional processing techniques such as machining, grinding, polishing, forming, and joining.

- Manufacturing processes for such difficult-to-process materials as ceramics, polymers, composites, sprayed materials, and superalloys.

- Nontraditional manufacturing processes (including hybrids) such as chemical vapor deposition (CVD), electrical discharge machining (EDM), electrochemical machining (ECM), electrochemical grinding (ECG), ultrasonic, microwave, laser, plasma, electron-beam, ion-implantation, and abrasive jet machining.

- Ultra precision machining.

- Near-net shape forming.

- New advanced cutting tools and die materials.

- Process modeling and sensors for on-line intelligent computer control of process parameters.

d. Next Generation Manufacturing Machines and Equipment—Research on integratable, intelligent equipment and machines that support automation systems and manufacturing processes. Specific areas include the following:

- Man-Machine interfaces that enhance the effectiveness of manufacturing people who are involved with vast information flows. Expert systems to support interactive decision making for future flexible manufacturing systems.

- Machines and equipment for individual unit processes, including research on machines and equipment to ensure their productive use as innovative improvements are made in materials and unit processes.

- Advanced machine tools, including research leading to more productive machine tools to produce parts of greater accuracy from materials more difficult to machine. Advanced, lightweight, and rigid machine components and structures from epoxy composites, ceramics, and other materials.

- Unattended manufacturing and automation systems new design strategies leading to the integration of machine elements and subsystems in an unattended environment.

- Sensors, including fusion of sensor data from similar and dissimilar sensors, high-speed data acquisition from multiple sensors, and neural net concepts specifically applied to advanced manufacturing machines and equipment to enable their rapid response to changing environments.

e. Manufacturing Systems—NSF is interested in operational issues such as cost and performance analysis, inventory management, production planning and control, scheduling, reliability, quality, facilities design, material handling, logistics, distribution and man-machine integration within the production environment. While the main focus of the program is on manufacturing systems, research with application to the full range of production systems including communication, transpor-tation, and distribution systems is also sought. Also of interest are advanced or innovative systems for production planning, scheduling, materials management, and distribution.

f. Service Systems—Design and manufacturing may be viewed as the inner loop that supports a broader activity responsible for much of the gross national product—the service industries. Some of the technologies derived from manufacturing systems, such as resource allocation and scheduling, and those associated with automation systems, such as networking and communication protocol, may be applied to automation in the service industries such as health care, banking, transportation, delivery, and maintenance.

g. Operations Research—Improved understanding and modeling of production systems will ultimately lead to better system design and operation and, consequently, to higher system performance. Research leading to the development of improved analytical and computational techniques for modeling, analysis, design, optimization, and operation of natural and man-made systems is supported. Research areas supported by the program range from new mathematical techniques to application-oriented algorithmic procedures. The areas of interest focus on large-scale integrated problems with a variety of tightly and loosely interconnected components that generally involve people, information, machines, and controls. Examples of specific areas of interest include basic research in optimization, scheduling, routing, location, simulation, queuing theory, statistics, and stochastic processes.

h. Integration Engineering—The goal is to provide a framework upon which a manufacturing enterprise operates and within which a number of components of engineering design, manufacturing, and sociotechnical aspects overlap. It has a design component in the context of cross-functional drivers that deal with product realization. Its mission, however, is broad and includes the complete product life cycle. Specific areas of interest include the following:

- Development and prototyping of operational systems and procedures that enhance the interface of design and manufacturing, including concurrent engineering research efforts.
- New quality paradigms at the enterprise level.
- Computer-integrated manufacturing methods and tools.
- Integrated manufacturing systems design.
- Agile manufacturing theory, principles, tools, and demonstrations.

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22. CHEMICAL AND TRANSPORT SYSTEMS

A. Scope of Research

The *Division of Chemical and Transport Systems* supports research contributing to the knowledge base for a large number of industrial processes involving the transformation and transport of matter and energy. The

research lays the foundation for technological innovation in many manufacturing industries, including petrochemical, advanced materials, environmental systems, aerospace, electronics and communications, power production, natural resources, biochemical, materials, food, pharmaceutical, and allied industries that use chemical, biochemical, and thermal processes. Research support is organized in the following areas: kinetics and catalysis; process and reaction engineering; interfacial, transport, and thermodynamics processes; particulate and multiphase processing; separation and purification processes; thermal transport and thermal processing; and combustion and thermal plasmas.

B. Suggested Subtopics

Proposals may be submitted on any subject within the programs of the ***Division of Chemical and Transport Systems***. Proposals on the following subtopics, however, are of particular interest:

a. Photochemical and Electrochemical Processes—Examination of processes using radiation or electric current to effect chemical reaction, including principles for design of industrial-scale reactors for such processes. Included in the scope are photocatalytic and electrocatalytic systems. Prime interest is in processes suitable for commercial chemical production or for environmental control.

b. Heterogeneous Catalysis—Generation of new catalysts or catalytic systems, or new uses for known catalysts, with applications in consumer products, environmental control, and chemicals production. ***[Note: Proposals relating to fuels production or utilization should be submitted to the Department of Energy rather than to NSF.]*** Of particular interest are systems with promise of reducing the release of acid-rain precursors and/or greenhouse gases or systems for the production of high-value-added products, including pharmaceuticals.

c. Chemical Process Design and Control—Research on the control of chemical plants and studies of new design strategies for complex integrated chemical processes as well as for system optimization. Software development, for example, is an appropriate area of investigation.

d. Separation and Purification Processes—Since separation is often a major cost of chemical processing, improved and new separation processes are increasingly important. Emerging technologies such as bioengineering and electronic materials processing are primary examples of application areas where cost-effective separations are critical. Research of interest encompasses highly selective, energy-efficient, and economic processes and mass separating agents for the separation and purification of all types of substances. Example areas of support include supercritical extraction, membrane processes, desalination, filtration, adsorption and chromatography, absorption, ion exchange, fractionation, and crystallization. Research in novel separation processes and those based on a combination of various techniques is encouraged. Specific areas of ongoing emphasis include the following:

- Energy-efficient separation and purification of organics (e.g., olefins).
- Environmentally benign separation processes.
- Recovery of critical and strategic metals.

Research on fuel cell membranes is not appropriate for this subtopic area.

e. Interfacial, Transport, and Thermodynamic Phenomena—Recent needs and developments in information storage have led to an examination of small aggregates of molecules that exhibit unusual interfacial and transport properties. Small businesses can play a major role in applying this scientific concept to the design of artificial layers and structures at the molecular level; in the design of chemical processes for new organic and inorganic chemicals and materials; and in making phase equilibria and transport predictions for environmentally hazardous chemicals. Examples of relevant research are the following:

- Preparation and thermodynamic characteristics of micellar and microemulsion fluid systems as templates for solid electronic or separation microstructures.

- Transport characteristics, processing, and fabrication of vesicular and liposomal clusters for patterned deposition for fluid systems.

- Langmuir-Blodgett film or other interfacial processing related to interfacially dominated applications, such as printing lithography, coatings, printing, and/or sensors.

- Interfacial diffusion processes between two layers and experimental analysis and modeling of the process.

f. Fluid, Particulate, and Hydraulic Systems—Supports research on mechanisms and phenomena governing single and multiphase fluid flow, particle formation and transport, and fluid-particle system characterization. No bias exists with respect to methods, whether analytical, numerical, experimental, or a combination of these. Research is sought that aims at markedly improving our understanding of important fluid engineering processes or phenomena, and/or that creates advances with high potential for significant industrial and environmental impacts. Since fluid and particulate behavior control many processing and manufacturing technologies, the desired impact is improvement in the predictability, precision, and control of existing systems, as well as in the suggestion of entirely new ones. Research support areas under this program include the following:

- Large Reynolds number flow.

- Density stratified flows.

- Flow of complex fluids.

- Deliberate production and/or modification of small particles with controlled properties, via colloids, aerosols, or crystallization.

- Particle attachment to or removal from surfaces.

- Efficient removal of particles from processing streams or plant effluents; efficient separation of particles based on size, bulk composition, or surface composition.

- Multiphase processes.

g. Thermal Transport and Thermal Processing—Innovative concepts and novel devices which relate to the utilization and transport of thermal energy, and to the manipulation of thermal history and thermal gradients to accomplish engineering and manufacturing goals. Examples of the former include novel techniques or devices to achieve ultra-high flux heating or cooling and new concepts of thermal insulation. Examples of the latter include new thermal methods of producing parts and materials of desired shape or properties, such as novel thermal molding methods and devices and rapid quenching/forming methods of producing nonequilibrium materials of superior microstructure and novel properties.

h. Combustion and Thermal Plasmas—Innovative concepts that can lead to clean and efficient combustion of gaseous, liquid, and solid fuels, with a concurrent reduction of pollutants. Also of interest are the combustion processes in low-grade fuels and toxic materials, with a view toward an improvement in current combustor/incinerator technologies.

- The use of combustion reactions to synthesize a specific product, as opposed simply to liberate heat, is an area of growing interest. The fundamental phenomena controlling the production of high-temperature materials through solid-solid and solid-gas combustion reactions are subjects in need of study.

- Engineering research into plasma dynamics and chemistry, transport processes in ionized gases, interaction of plasmas with boundaries, and diagnostic techniques in high-temperature media is supported by the program. Interest is limited to the investigation of new concepts and ideas involving nonequilibrium thermal plasmas.

i. Chemically Benign Manufacturing—This is a relatively new area in which proposals are also being sought. These proposals need to address pollution prevention or reduction, not waste treatment. Projects should focus on chemical and synthetic processes and should be design-oriented as opposed to analytical and computer-oriented. Typical ideas might include the following: alternative chemical syntheses that bypass

toxic feedstocks and solvents, improved membranes and membrane/molecular sieve technologies that integrate selective catalysts to reduce by-product formation, and new chemistries for on-demand, on-site production and consumption of toxic intermediates in manufacturing. Proposals that address processes to remove pollutants from waste streams or that address conventional end-of-pipe environmental engineering are not responsive to this interest.

23. CIVIL AND MECHANICAL SYSTEMS

A. Scope of Research

The ***Division of Civil and Mechanical Systems*** supports research driven both by intrinsic interest in various phenomena and by the need for solutions to problems in civil and mechanical engineering, mechanics, and materials. Problems of interest are related to the design and behavior of mechanical systems, structures, geo-systems, and building systems. Research focus is placed on the analysis and synthesis of mechanical and building component systems, including surface engineering, tribology, dynamics, geomechanics, and improved materials that must perform in extreme environments.

The Division also supports research to strengthen and implement the knowledge base on the following subjects: (1) the physical phenomena of natural hazards such as earthquakes, hurricanes and tornadoes, floods and droughts, landslides, subsidence and other ground failures; (2) the interactions of natural hazards with, and their impacts on, populations, the natural environment, and constructed facilities; (3) methods of assessing the nature, magnitude, risk, and costs of these impacts; (4) the prediction of natural hazard occurrences (except earthquakes); and (5) the creation and dissemination of technical information for mitigating and preventing the consequences of disasters.

B. Suggested Subtopics

Although any proposal within the general scope of research of the Division may be considered, the following subtopics are of particular interest.

a. Mechanics and Materials—Proposals are sought in the design, mechanical response, and failure of all classes of solids. Theoretical, experimental, and computational investigations of deformation, fatigue, and fracture behavior, accounting for the underlying phase, defect, and microstructural state and its origin, transformation, and evolution are emphasized.

- Constitutive equations and damage, including experimental, computational, and analytical investigations into the manner in which solid materials and composites deform (stress-strain relations) and fail (damage mechanics, fracture mechanics, fatigue) under static and dynamic uniaxial and multiaxial states of stress and various thermal environments. These include the following: the analytical modeling of experimentally observed phenomena; correlation of experimental observations with analytical predictions; and integration between the macroscopic approach of continuum mechanics and the microscopic approach of materials science. Research that bridges the traditional boundaries between solid mechanics and materials science and engineering is encouraged.

- Materials processing and manufacturing, including modeling and computer simulation of thermal and/or mechanical aspects of materials processing and manufacturing, spanning the range of new understanding of the older, well-established processes to new processes, including those involving smart, optical, and electronic materials and devices.

- Biomechanics, including advances in solid mechanics combined with contributions of biology, physiology, medical science, and medical practice. Clinical research is **not** supported. Collaboration with life scientists is encouraged.

b. Structures, Geomechanics, and Building Systems—Innovative and progressive methods are sought in design, construction, maintenance, and operation of safe, long-lived, efficient, and economical civil engineering systems and facilities including their total performance. Also sought is research on a deteriorating

civil infrastructure and actions that can be taken to diagnose, repair, restore, retrofit, and enhance the performance of existing constructed facilities.

- Structural mechanics, including research in static and dynamic structural mechanics, analysis, optimization, and design procedures and in construction materials, including cement chemistry, concrete, steel, and wood mechanics. Emphasis is placed on deterioration sciences, computational numerical procedures, intelligent structures, and materials.

- Construction engineering, bridges, and building research, including new concepts for building analysis and design practices and procedures used in the construction of engineered facilities and used in the design, construction, operation, utilization, and condition assessment of buildings and bridges, and in renewal engineering.

- Geomechanical, geotechnical, and geo-environmental, systems involving research aimed at the behavior of geomaterials in ambient, subterranean, offshore, hazardous, and extraterrestrial environments. Emphasis is currently on construction and stability of geo-structures (including underground space), multiphase groundwater flow and contaminant transport in geomaterials, soil-structure interaction, transferability of laboratory-scale measurements and concepts to field scale, "intelligent" geocomposites, calibration systems, large-scale database management, knowledge-based expert systems for optimal design strategies, quality and performance of geo-systems, and computer-aided construction to increase optimization and reliability of geo-structures.

- Nondestructive evaluation (NDE) and *in situ* testing (IST). In the context of structural integrity, research is needed in the determination of safe loads, design, lifetime, and damage tolerance of components and constructed systems. Proposals may address advances in related fields such as magnetism, acoustics, and assessment technologies. The latest advances in solid mechanics and geomechanics should be addressed in proposals. There is special interest in quantitative techniques that provide information on defects. Monitoring of materials and systems by fiber optics and other techniques are included in this category.

c. Dynamic Systems and Control—Research on the dynamic behavior and control of machines, processes, structures, and vehicles, including physical modeling of all types of dynamic systems to improve the knowledge base for analyzing performance and control. Areas of particular interest include the following:

- Dynamic system modeling and simulation.

- Improved analytical and experimental techniques for kinematics and dynamics of machines.

- Noise and vibration suppression.

- Control of nonlinear systems.

- Sensor and actuator dynamics and control.

- Intelligent control of multibody mechanical systems.

d. Surface Engineering and Tribology—Research on the characterization, structure, properties, modification, behavior, and life prediction of surfaces; corrosion, friction, tribosensing and wear; lubrication and modeling of tribosystems; and coatings and tribomaterials. Current emphasis is on innovative research leading to new ways of generating or characterizing surfaces that are engineered for optimal mechanical properties, topography, and microstructure leading to improved tribological materials, lubricants, and coatings for operation under severe conditions. Modeling of tribosystems and the use of signals from tribological events for tribosensing and process control are also supported as well as tribological problems in materials processing and manufacturing.

e. Earthquake Hazard Mitigation—Research to minimize the impacts of earthquakes, including investigation of ground motion and ground failure due to earthquakes for different kinds of sites; development of

analytical methods for prediction of effects on structures, lifelines, and foundations and for the experimental verification of predictions; new passive and active systems of sensors and instruments for monitoring and control of structural motions; improved ways of designing earthquake-resistant structures; new methods for reducing the impact of tsunamis on coastal areas and structures; and dissemination of research results to users.

f. Natural and Technological Hazard Mitigation—NSF seeks new knowledge needed to design engineering systems that cope with natural hazards such as extreme floods and droughts, hurricanes and tornadoes, accelerated erosion, wind and water, ice jams and snow drifts, landslides, subsidence, and expansive soils.

g. Civil Infrastructure Systems Research—The nation's infrastructure comprises several large and complex engineering systems, which interact with each other in ways that are not very well understood. Past research has concentrated on the operation and performance evaluation of individual components within separate systems. Research proposals addressing deterioration, assessment, and renewal methods affecting the systemic performance of the nation's civil infrastructure systems are sought.

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24. BIOENGINEERING AND ENVIRONMENTAL SYSTEMS

A. Scope of Research

The ***Bioengineering and Environmental Systems Division*** supports research to expand the knowledge base of bioengineering, to apply engineering principles for prevention of the pollution of land, air, and water resources, to remediate those that have been adversely affected by environmental pollutants, and to develop, conserve, and use ocean resources and engineering systems. The relatively new cross-disciplinary field of bioengineering applies engineering principles to the understanding of living systems, development of new devices and products for human health care, and development and production of new products derived from advances in biology. The Bioengineering and Environmental Systems Division contains five programs, Biochemical Engineering, Biotechnology, Biomedical Engineering and Aiding the Disabled, Environmental Systems, and Ocean Systems.

B. Suggested Subtopics

a. Biochemical Engineering—Proposals are sought in the design and development of traditional, rDNA, and plasma fractionation processes for bioproduct manufacture. Biomass projects utilizing microorganisms for the transformation of organic raw material to useful products, such as ethanol, are sought. Projects in food process engineering involving fermentation technology are of special interest.

- Molecular and cellular engineering. This expanding area of engineering research encompasses pure and mixed culture processes, modeling and optimization of cell and metabolite production, development of new biochemical reactors, protein engineering, and the conversion of synthetic gas and other chemical feedstocks to value-added products through biological means. New techniques in the monitoring and control of molecular and cellular engineering are also of interest.

- Biomass processing in which emphasis is on new engineering knowledge for transforming organic raw materials (biomass) into useful constituents. Specifically, innovations are sought in biological conversion of renewable materials into useful end products, biological separation of biomass components (cellulose, hemicellulose, lignin, and other natural polymers), methods for producing high-value chemical constituents from algae and microbes, and biomass utilization with genetically engineered organisms.

- Food processing research that focuses on fermentation processes and other uses of biologicals for the conversion and/or manufacture of important food products. Consideration will also be given to more conventional food processing strategies and projects involving marine aquaculture.

- Downstream processing. Efficient separation and purification of bioproducts on a commercial scale are controlling steps in the bioprocessing of high-value-added products such as therapeutics in human health care. New processes and major enhancements of existing processes are needed.

  Downstream processing includes at least four sequential steps: (1) removal of insolubles, (2) isolation of products, (3) purification, and (4) polishing. To carry out these steps, many

techniques must be explored. Technologies of interest include but are not limited to the following:

- Immuno-affinity chromatography.
- Electrophoresis.
- Aqueous two-phase systems.
- Selective precipitation.
- Ultrafiltration.
- Membrane technology.
- Ion exchange techniques.
- Reversed micellular recovery processes.
- High-pressure liquid chromatography.
- Upstream enhancements.
- Process monitoring and control.

Transforming these technologies from laboratory to production scale is a great engineering challenge. Not only are the above problems of concern, but the heat and sheer sensitivity of proteins makes the task even more difficult.

b. Biotechnology—Linking the expertise of engineering with the life sciences is crucial to the economical manufacture of products of biological origin. An increasing flow of products from genetic engineering and cell fusion technology now reach the marketplace. Novel bioprocess engineering, both upstream and downstream, is needed for economic production. Often, engineers and life scientists, broadly competent in their own fields, must collaborate in this research.

One focus is problems of production and processing of substances requiring a thorough knowledge of modern molecular biology. New and creative ideas as well as cross-disciplinary efforts to solve these problems are encouraged.

Specific research emphases for fundamental studies include but are not limited to the following:

- Cell culturing systems, including new fundamental engineering knowledge of cellular processes for making substances of biological origin. This includes systems capable of culturing normal and genetically altered cells.

- New understanding of the use of proteins, cells, or other biological material in the design and scale-up of novel biological reactors.

- Separation and purification processes, including expanded engineering knowledge of commercial-scale separation and purification of complex and often unstable substances obtained from cell culturing systems and/or novel bioreactors.

- New techniques for monitoring the metabolic state of cells in a culture as well as the status of conditions within a cell culturing system, a bioreactor, or separation and purification processes for products obtained from cell culturing systems and/or bioreactors. Design and implementation of sensing devices based on these studies are invited. Process control algorithms enabling using these monitoring techniques are needed for optimizing biological processes.

c. Biomedical Engineering and Aiding the Disabled (BMEAD)—The BMEAD subtopic supports biomedical engineering research for characterization, restoration, or substitution of normal function in humans. This subtopic focuses on advancing research knowledge in biomedical engineering rather than on the solution of specific disease-oriented problems. Proposals should lead to new technologies or to novel applications of existing technology.

Areas of interest include but are not limited to the following:

- Significant improvements in deriving information from cells, tissues, organs, and organ systems. Examples are biosensors, noninvasive

instruments, ultrasound, microwave, and new imaging modalities.

- Extraction of useful information from complex biomedical signals and data. Examples include time-frequency distributions, adaptive neural network architectures based on biological systems, statistical pattern recognition, three-dimensional image reconstruction, and mathematical modeling.

- New approaches to the design of structures and materials for eventual medical use. Examples are biocompatible surfaces, bone healing, wound healing, tissue engineering, implantable devices, and aids for the disabled.

- New methods for the application of control systems technology. Examples are design of biologically inspired control system architectures, drug delivery systems, functional electrical stimulation, and critical care monitoring and control.

- New technology to reduce the cost of health care without reducing quality of care. Examples include the application of technology to develop new systems for improved productivity in the health care system and reduced personnel costs; technology for new low-cost measurement and monitoring systems intended for remote sites; expert and knowledge-based systems for standardized diagnosis and treatment; cost-effective means to link patients, providers, care facilities, and homes; development of improved information and communication systems to provide a uniform, rapid, and data-secure access to patient medical histories; and improved methods to aid in the assessment of outcomes associated with new cost-effective health care technologies.

d. Environmental Systems—Research is sought in applications of engineering principles for prevention of the pollution of land, air, and water resources and for the remediation of those that have been adversely affected by environmental pollutants. New knowledge is needed on the following subjects: the diffusion, dispersion, and interactions of pollutants; innovative water and wastewater treatment processes and systems; and engineering approaches to manage or eliminate discharges that degrade environmental quality. Proposals are **not** sought for research on the regulation of pollutants, improved monitoring for compliance with existing regulations, regulatory enforcement, or environmental policy issues. Techniques are sought to disinfect and decontaminate water; to control physical, chemical, and biological treatment processes; and to manage products and by-products from treatment systems.

Areas of special interest within this subtopic include the following:

- Uses of ionizing radiation (ultraviolet, gamma, electron beam, and X-ray) for disinfection and decontamination of water, for treatment of solid, liquid, and gaseous emissions, and for destruction of environmentally hazardous substances.

- Technologies especially appropriate for investigations and/or engineering design of systems that address waste processing and management problems that are unique to U.S. coastal regions.

e. Ocean Systems—NSF seeks fundamental engineering knowledge of the ocean environment and technological innovations related to the conservation, development, and use of the oceans and their resources in an environmentally acceptable manner. Proposals are invited for fundamental or exploratory research and for feasibility studies to advance engineering and scientific knowledge of the oceans. **Commercial product development is not supported.**

Proposals are invited in all areas of ocean engineering, e.g., electrical, chemical, mechanical, civil, bioengineering, and engineering aspects of mariculture. Proposals may address needed engineering knowledge to stimulate and facilitate new technology for the development of resources, such as energy, minerals, and fisheries and the uses of the oceans, such as transportation, power generation, communication, and waste management.

Specific areas include but are not limited to the following:

- Advanced ocean-based platform/systems including autonomous undersea vehicles, subsea robotics, and other instrumented and remotely operated systems for characterization of the ocean environment, seafloor, and subseafloor; and for the development and utilization of ocean resources.

- Advanced sensing and measurement techniques and systems for ocean resource survey, assessment, and efficient extraction and for monitoring the ocean environment for its protection and conservation.

- New or composite materials with special properties for reliable use in the ocean environment considering such factors as fatigue and corrosion, effects of biofouling, temperature cycling, and high pressure.

- Advanced techniques for sensing, processing, and communicating ocean and seafloor data.

- Synthesis and design methodology for very large scale ocean platforms and structures such as artificial islands and floating facilities for multiple uses.

- Ocean energy and ocean energy conversion techniques, undersea power sources, and propulsion techniques.

- Engineering research utilizing new scientific advances in marine biotechnology for new materials composed of marine organisms and for development and improvement of ocean grown and harvested products.

- Coastal Ocean Space Utilization Research with emphasis on resource recovery, port and harbor infrastructure, and environmental monitoring and remediation in coastal waters.

References

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Bekey, G.; Katona, P.; Eds. May 16-18, 1990. Bio-control by neural networks: summary of a workshop supported by the National Science Foundation.

Massachusetts Institute of Technology Sea Grant College Program. April 1986. Public waste management and the ocean choice. MIT SG 85-86. Cambridge, MA: MIT.

National Research Council, Water Science and Technology Board. 1993. Managing wastewater in coast urban areas. Washington, DC: National Academy Press.

National Science Foundation, American Academy of Environmental Engineers. April 9-12, 1994. Environment quality and industrial competitiveness: proceeding of the workshop on environmental issues related to industrial competitiveness. [132 Holiday Court, Suite 206, Annapolis, MD 21401.]

University of Miami. 1984. Disinfection of wastewater effluents and sludes, state-of-the-art and research needs. Conference Proceedings. NTIS No. PB 87-206223.

25. EDUCATION AND HUMAN RESOURCES

A. Scope of Research

The *Education and Human Resources Directorate* seeks to provide leadership in improving the quality of science, mathematics, engineering, and technology education for all students (prekindergarten through graduate studies); to increase the participation of underrepresented populations (women, minorities, and persons with physical disabilities) in the scientific enterprise; and to expand opportunities for the public understanding of science and technology. Proposals submitted under this subtopic should support the five major long-term goals of the Directorate:

- To ensure that a high-quality formal education in science, mathematics, and technology is available to every child, both to enable those who are interested and talented to pursue scientific and technical careers at all levels, as well as to provide a base of understanding by all citizens.

- To ensure that educational pipelines carrying students to careers in science, mathematics, engineering, and technology yield sufficient numbers of well-educated individuals to meet the needs of the U.S. technical workforce.

- To ensure that those who select scientific, engineering, and advanced technology careers have available the best possible professional education in their respective disciplines.

- To ensure that opportunities are available at the college level for interested nonspecialists to broaden their scientific and technical backgrounds.

- To ensure that informal science education opportunities are available that maintain public interest in, and awareness of, scientific and technological developments.

B. Suggested Subtopics

High technology has revolutionized many segments of the economy. While showing great potential for the education sector, its impact has been limited. Emerging technologies can play an important role in enhancing student learning and participation in research and technology. Emphasis should be on development of hardware or software that demonstrates promise in (1) improving the learning of scientific and technical principles, as well as problem solving at all education levels; (2) broadening access to quality science and technology education; and, (3) promoting equal access for those with physical disabilities. ***[Note: Research on the reading process and learning to read through computer-aided and other means should be addressed to Topic 14.h.]***

Categories of proposals most strongly encouraged are as follows:

a. Development of Low-Cost Instrumentation or Data Acquisition Equipment—to facilitate classroom teaching and learning or laboratory research by students.

b. Development of Computer or Multimedia Software—to enhance student learning and promote student interest in science or technology, e.g., intelligent tutors, tools, and virtual reality.

c. Development of Hardware and/or Software—to promote networking of students, teachers, and practicing scientists, engineers, and technologists, e.g., distance learning, electronic data transfer, and networking.

d. Specialized Educational Equipment for Persons with Physical Disabilities—e.g., adaptive equipment, methods, and technologies that aid in the delivery, support, or access of quality education in scientific or technical disciplines.

Proposals are generally grouped by content area and targeted grade level and then reviewed by a panel of individuals with an appropriate mix of disciplinary, education, and technology expertise. To assist in identifying a panel most appropriate for review of your proposal, you should indicate both the content category of the subtopic (a-d, as shown above) and the educational level (1-5, as shown below). Education categories are as follows:

(1) Elementary (grades K–5).

(2) Middle school (grades 6–8).

(3) Secondary school (grades 9–12).

(4) Undergraduate (both two- and four-year institutions) and graduate education.

(5) Public science literacy.

If, for example, your proposal primarily concentrates on development of interactive software for use in museums and informal science settings, you should indicate this by

categorizing it as "b-5" on the cover page of the proposal under the box labeled "subtopic letter."

C. Evaluation Criteria

Proposals submitted under this subtopic should be focused on the development of innovative hardware and software and their application to science, mathematics, engineering, and technology education. In addition to the five general research evaluation criteria specified earlier in this solicitation, the following must be addressed, as appropriate.

a. Clear identification of need and demonstrated promise of the product for improving the state of current educational technologies.

b. Demonstrated knowledge and incorporation of accepted content standards in science, mathematics, engineering, and technology.

c. Awareness of sound pedagogical techniques and developmentally appropriate content and instructional strategies.

d. Demonstrated involvement (on both advisory committees and/or staff) of science, mathematics, engineering, and technology educators at appropriate grade levels.

e. Ease of transportability (i.e., replication across sites) and scalability (i.e., increasing the number of users) to maximize impact on the education community.

f. Promise of providing a cost-effective product which will promote adoption and implementation in schools and universities.

26. TECHNOLOGIES RELEVANT TO NEXT GENERATION VEHICLES

A. Scope of Research

For many years, NSF has funded a wide variety of basic research proposals with potential relevance to the automobile industry. This year, proposals in this category will receive special attention, in response to the President's Next Generation Vehicle (NGV) initiative.

NGV activities will be funded by many agencies, in many different contexts. In order to avoid duplicating other efforts, the NSF SBIR activity will focus on high-risk efforts aimed at the most long-term, high-potential aspects of this initiative, leveraging advanced technologies emerging from existing NSF programs. These efforts include basic technical and economic issues important to the transition to fuel cell or electric automobiles with performance characteristics acceptable to the average consumer which, at a minimum, include acceptable costs and a driving range of at least 300 miles. Testbed applications of short-term value to industry are certainly acceptable, but the evaluation will be based on the long-term potential and uniqueness of the work relative to what is already funded elsewhere. NSF will not support commercial vehicle development, but it will give priority to research proposals that demonstrate that their results, **if successful**, would be valuable to industry. Equal priority will be given to projects that would ultimately lead to better vehicle designs and to projects that would reduce the lead time or cost in manufacturing such vehicles and their subsystems. Priority will also be given to projects that lead to a predictive understanding of market and society-wide implications. Regardless of research focus, priority will be given to new collaborations across disciplines and/or institutions.

For more information on the long-term aspects of the NGV initiative, consult the White House Technology Plan of February 22, 1993. During the spring of 1994, a report may become available from the NSF-DOE workshop of December 1993 on Research Issues in the Transition to Fuel Cell or Electric Automobiles for the Average Cost Consumer. (Call Dr. Paul J. Werbos at (703) 306-1339.)

NSF will consider a wide range of advanced research topics within the following general areas. Issues relating to the projection and reduction of costs and management of uncertainty are of central importance to industry. These issues are of relevance to all of the subtopics noted below.

This list of subtopics is intended to be illustrative, not comprehensive.

B. Suggested Subtopics

a. Membrane Research—Improvement and analysis of membranes used in fuel cells, with particular emphasis on proton exchange membranes (PEM). The objective here is to develop new membranes, capable of being used in very compact fuel cells, as is the Nafion™ membrane from Dupont. The ultimate goal is to develop membranes with improved capabilities, particularly in regard to cost, performance, lifetime, power density, and tolerance of a broad range of operating conditions. Fundamental research that leads to a better understanding of these characteristics can also be supported.

b. Intelligent Control, Sensors, and Systems Integration—Advanced control designs applicable to a next generation automobile or to major subsystems, such as the engine or powerplant. For example, some researchers have argued that the quality of thermal control may be important to reducing the size of fuel processors—used to convert natural gas to hydrogen on board a car—to be injected into a fuel cell. Research using benchmark versions of this control problem, using or upgrading new intelligent control designs, could be of great interest. Reports on natural gas and methanol reformers are available from Los Alamos National Laboratories and from Arthur D. Little (ADL), based on work supported by DOE. Some of the NSF-supported work in intelligent control is described in the *Handbook of Intelligent Control*, White and Sofge (eds.), Van Nostrand, 1992. Development of solid-state, low-cost "intelligent sensors" for gas concentrations and other key variables, using on-chip pattern recognition, could be an important component of some research efforts on this subtopic.

c. Power Systems and Integration—Power management issues including control, power semiconductors, and strategies for coping with electromagnetic interference (EMI) associated with systems-level design of such vehicles. Los Alamos National Laboratories has published a number of papers describing some of these challenges. Also, Los Alamos published some alternative design concepts in the 1980's, using electrolysis to provide hydrogen for peaking power, which could provide an interesting benchmark for theoretical studies.

d. Catalysis—Improved catalysts for use in fuel cells. Lower cost alternatives to platinum, such as macrocyclic catalysts, and methods to reduce catalyst loading and increase power density, would be of great interest. Catalysts for the environmentally benign direct oxidation of methanol would also be of interest. NSF would also support highly theoretical work related to this topic, such as the development of molecular modeling and analysis tools, focused on the issue of improved capabilities to design such new catalysts or structures at minimum cost, for use by the general research community. There would be special interest in novel algorithms embodying the quantum mechanical calculations relevant to predicting the electrochemical properties of alternative molecules.

e. Manufacturing, Process Control, and Materials—Manufacturing technology for reduced-cost manufacture of critical NGV components, such as membranes, fuel cell stacks, fuel processors, and gaseous fuel storage systems. Issues ranging from manufacturing process control to use of alternative materials would be of potential interest, if the issue of manufacturing cost is credibly addressed. As an example, characterization of conductive polymers suitable for use as an alternative to bulky and heavy graphite plates in PEM fuel cell stacks would be one subtopic of interest.

f. Enterprise Integration and Design Technologies—Improved enterprise integration software, designed to minimize lead times in developing such vehicles. NSF already supports generic work in enterprise integration and CAD/CAM systems. There are special issues, however, in developing systems that facilitate anticipatory design for whole-systems cost and dynamic performance of NGV's, based on components that are only now being built. There are further issues in developing systems that could provide the backbone for collaboration between multiple enterprises and universities, using nationwide communications networks such as the NSFNET, INTERNET, or NREN. The management of property rights within such networks is of some importance; there are economic issues involved in maximizing efficiency, while maintaining the incentives of all parties. Use of intelligent control

techniques in simulation might also be used to assist design optimization with reference to dynamic test regimes.

g. Social and Economic Issues—Research needed to better understand the social and economic processes of a transition to a whole new fuel infrastructure, the issues involved in labor conversion, and the speed of adoption and technology diffusion.

h. Environmental Issues—Whole-systems environmental issues, ranging from recycling parts and fuel for a new class of vehicles to pollution control during and after fuel production. Environmental issues in the process of transition to a new fuel infrastructure are also of interest.

i. Alternative Fuel Production and Storage—DOE already supports considerable work in conventional techniques for storing hydrogen and natural gas and biomass technologies for producing hydrogen and methanol. There is some possibility, however, of NSF support for more radical, new approaches, using innovative biotechnology or for more basic understanding of the reasons why existing carbon storage techniques for hydrogen have not lived up to their projected potential. (DOE has verified the existence of the latter problem through independent tests conducted at Arthur D. Little, but the causes of and solutions to the problem require much deeper research.)

j. Other Important Subtopics—Because this initiative is new, there are undoubtedly other important topics related to the goals of this initiative. It should be emphasized, once again, that the list above is only a partial list, intended to be suggestive rather than comprehensive. Proposals on other subtopics must meet the following three criteria: (1) they must neither be so applied nor near-term that they duplicate existing work in industry or in other agencies; (2) they must convincingly explain how they would (if successful) improve the probability of success of the President's initiative; and (3) they must build on advanced research capabilities and novel approaches, leveraging the kind of advanced research normally supported by identifiable programs at NSF.

INFORMATION ABOUT PRINCIPAL INVESTIGATORS/PROJECT DIRECTORS

Submit only ONE copy of this form with your proposal. Attach it on top of the cover page of the copy of your proposal that bears the original signatures. Leave the back of the page blank. *Do not include this form with any of the other copies of your proposal, as this may compromise the confidentiality of the information.*

Please check the appropriate answers to each question for all principal investigator(s)/project director(s) listed on the cover page, using the same order in which they were listed there:

	Principal Investigator/ Project Director	First Additional PI/PD	Second Additional PI/PD	Third Additional PI/PD	Fourth Additional PI/PD
1. Is this person					
Female	☐	☐	☐	☐	☐
Male	☐	☐	☐	☐	☐
2. Is this person a					
U.S. Citizen	☐	☐	☐	☐	☐
Permanent Resident	☐	☐	☐	☐	☐
Other non-U.S. Citizen	☐	☐	☐	☐	☐
3. Which one of these categories best describes this person's ethnic/racial status? (If more than one category applies, use the category that most closely reflects the person's recognition in the community.)					
American Indian or Alaskan Native	☐	☐	☐	☐	☐
Asian	☐	☐	☐	☐	☐
Black, not of Hispanic Origin	☐	☐	☐	☐	☐
Hispanic	☐	☐	☐	☐	☐
Pacific Islander	☐	☐	☐	☐	☐
White, not of Hispanic Origin	☐	☐	☐	☐	☐
4. Does this person have a disability* which limits a major life activity?					
Yes	☐	☐	☐	☐	☐
No	☐	☐	☐	☐	☐
Check here if this person does not wish to provide some or all of the above information.	☐	☐	☐	☐	☐
Required: Check here if this person is currently serving (or has previously served) as PI, Co-PI or PD on any Federally funded project.	☐	☐	☐	☐	☐

AMERICAN INDIAN OR ALASKAN NATIVE: A person having origins in any of the original peoples of North America, and who maintains cultural identification through tribal affiliation or community recognition.

ASIAN: A person having origins in any of the original peoples of East Asia, Southeast Asia or the Indian subcontinent. This area includes, for example, China, India, Indonesia, Japan, Korea and Vietnam.

BLACK, NOT OF HISPANIC ORIGIN: A person having origins in any of the black racial groups of Africa.

HISPANIC: A person of Mexican, Puerto Rican, Cuban, Central or South American or other Spanish culture or origin, regardless of race.

PACIFIC ISLANDER: A person having origins in any of the original peoples of Hawaii; the U.S. Pacific Territories of Guam, American Samoa, and the Northern Marianas; the U.S. Trust Territory of Palau; the islands of Micronesia and Melanesia; or the Philippines.

WHITE, NOT OF HISPANIC ORIGIN: A person having origins in any of the original peoples of Europe, North Africa, or the Middle East.

*Disabled: A person having a physical or mental impairment that substantially limits one or more major life activities; who has a record of such impairment; or who is regarded as having such impairment.

WHY THIS INFORMATION IS BEING REQUESTED:

The Federal Government has a continuing commitment to monitor the operation of its review and award processes to identify and address any inequities based on gender, race, ethnicity or disability of the proposed principal investigators/ project directors and co-principal investigators. To gather the information needed for this important task, you should submit a single copy of this form with each proposal; however, submission of the requested information is not mandatory and is not a precondition of award. Any individual not wishing to provide the information should check the box provided for this purpose. (The exception is information about previous Federal support, the last question above.)

Information from this form will be retained by Federal agencies as an integral part of their Privacy Act Systems of Records in accordance with the Privacy Act of 1974. These are confidential files accessible only to appropriate Federal agency personnel and will be treated as confidential to the extent permitted by law. Data submitted will be used in accordance with criteria established by the respective Federal agency for awarding grants for research and education, and in response to Public Law 99-383 and 42 USC 1885c.

NSF Form 1225 (1/90)

NATIONAL SCIENCE FOUNDATION

APPENDIX B

SBIR PROPOSAL COVER PAGE

Small Business Innovation Research
Program Solicitation No. 94-45
CLOSING DATE: JUNE 13, 1994

TOPIC NO.	SUBTOPIC LETTER (If any)	TOPIC TITLE
PROPOSAL TITLE		
NAME OF PROPOSING SMALL BUSINESS CONCERN	ADDRESS (Including ZIP CODE)	
REQUESTED AMOUNT $	PROPOSED DURATION **6 months**	PERIOD OF PERFORMANCE **January 1–June 30**

THE SMALL BUSINESS CONCERN CERTIFIES THAT:	Y/N
1. It is a small business as defined in this solicitation.	
2. It qualifies as a socially and economically disadvantaged business as defined in this solicitation.FOR STATISTICAL PURPOSES ONLY	
3. It qualifies as a women-owned business as defined in this solicitation. FOR STATISTICAL PURPOSES ONLY	
4. It has submitted an equivalent proposal to another Federal agency. If YES, provide required information as outlined in the solicitation.	
5. A minimum of two-thirds of the research will be performed by this firm in Phase I.	
6. It will permit the government to disclose the title and technical abstract page, plus the name, address and telephone number of a corporate offical if the proposal does not result in an award to parties that may be interested in contacting you further information or possible investment.	
7. It will comply with the provisions of the Civil Rights Act of 1964 (P.L. 88-352) and the regulations pursuant thereto.	

PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR

NAME	
SOCIAL SECURITY NO.	TELEPHONE NO. ( )

COMPANY OFFICER (FOR BUSINESS AND FINANCIAL MATTERS)

NAME	TELEPHONE NO. ( )

OTHER INFORMATION

PRESIDENT'S NAME	YEAR FIRM FOUNDED	NUMBER OF EMPLOYEES AVERAGE PREVIOUS 12 MO.: CURRENTLY:

PROPRIETARY NOTICE See Section 7.4 for instructions concerning proprietary information.
Proprietary Information is contained on pages ________________ of the proposal.
NOTE: The signed Certification Page must be included immediately following this Cover Page with the original copy of the proposal only.

Proposal Page No. 1

NSF FORM A (3/94)

CERTIFICATION PAGE

APPENDIX B (continued)

Certification for Principal Investigators and Co-Principal Investigators:

I certify to the best of my knowledge that:
(1) the statements herein (excluding scientific hypotheses and scientific opinions) are true and complete, and
(2) the text and graphics herein as well as any accompanying publications or other documents, unless otherwise indicated, are the original work of the signatories or individuals working under their supervision. I agree to accept responsibility for the scientific conduct of the project and to provide the required progress reports if an award is made as a result of this application.

I understand that the willful provision of false information or concealing a material fact in this proposal or any other communication submitted to NSF is a criminal offense (U.S. Code, Title 18, Section 1001).

Name (Typed)	Signature	Date
PI/PD		
Co-PI/PD		
Co-PI/PD		
Co-PI/PD		

Certification for Authorized Company Representative

By signing and submitting this proposal, the individual applicant or the authorized official of the applicant institution is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding Federal debt status, debarment and suspension, drug-free workplace, and lobbying activities (see below), as set forth in Grant Proposal Guide (GPM), NSF 94-02. Willful provision of false information in this application and its supporting documents or in reports required under an ensuing award is a criminal offense (U.S. Code, Title 18, Section 1001).

Debt and Debarment Certification (If answer "yes" to either, please provide explanation.)

Is the organization delinquent on any Federal debt? Yes ___ No___
Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department of agency? Yes ___ No___

Certification Regarding Lobbying

This certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding $100, 000 and for an award of a Federal loan of a commitment providing for the United States to insure or guarantee a loan exceeding $150,000.

Certification for Contracts, Grants, Loans and Cooperative Agreements

The undersigned certifies, to the best of his or her knowledge and belief, that:

(1) No federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.
(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress or any employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form LLL, "Disclosure Form to Report Lobbying," in accordance with its instructions.
(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

AUTHORIZED COMPANY REPRESENTATIVE		SIGNATURE	DATE
NAME/TITLE (TYPED)			
TELEPHONE NUMBER	ELECTRONIC MAIL ADDRESS		FAX NUMBER

DO NOT DUPLICATE THIS PAGE AS PART OF THE PROPOSAL

Every prospective grantee must complete the section on certifications on the cover sheet (NSF Form 1207, rev 10/88) submitted with each proposal. Instructions for the two certifications are below:

INSTRUCTIONS ON CERTIFICATION ON NON-DELINQUENCY BY APPLICANTS FOR FEDERAL ASSISTANCE

Pursuant to OMB circular A-129, "Except where required by law or approved by the head of the agency, no award of Federal funds shall be made to an applicant who is deliquent on a Federal debt until the deliquent account is made current or satisfactory arrangements are made between affected agencies and the debtor." The certification of non-deliquency applies only to the organization requesting financial assistance and not to the individual Principal Investigator.

For the purposes of this certification, the following definitions of deliquency apply:

Direct loans - a debt more than 31 days past due on a scheduled payment.

Grants - recipients of a "Notice of Grants Cost Disallowance" who have not repaid the disallowed amount or who have not resolved the disallowance.

Guaranteed and insured loans - recipients of a loan guaranteed by the Federal Government that the Federal Government that the Federal Government has repurchased from a lender because the borrower breached the loan agreement and is in default.

Examples of debts include ddeliquent taxes, audit disallowances, guaranteed and direct student loans, housing loans, farm loans, business loans, Department of Education institutional loans, benefit overpayments and other miscellaneous administrative debts.

INSTRUCTIONS ON CERTIFICATION REGARDING DEBARMENT AND SUSPENSION

1. By signing and submitting this proposal, the prospective primary particpants is providing the certification set out below.

2. The inability of a person to provide the certification required below will not necessarily result in denial of participation in this covered transaction. the prospective participant shall submit an explanation of why it cannot provide the certification set out below. The certification or explanation will be considered in connection with the department or agency's etermination whether to enter into this transaction. However, failure of the prospective primary participant to furnish a certification or an explanation shall disqualify such person from particiaption in this transaction.

3. The certification in this clause is any material representation of fact upon which reliance was placed when the department or agency determined to enter into this transaction. If it is later determined that the prospective primary participant knowingly rendered an erroneous certification, in addition to other remedies available to the Federal Government, the department or agnecy may terminate this transaction for cause of default.

4. The prospective primary participant shall provide immediate written notice to the department or agency to whom this rpoposal is submitted if at any time the prospective primary participant learns that its certification was erroneous when submitted or has become erroneous by reason of changed circumstances.

5. The terms *covered transaction, debarred, suspended, ineligible, lower tier-covered transaction, participant, person, primary covered transaction, principal, proposal,* and *voluntarily excluded,* as used in this clause, have the meanings set out in the Definitions and Coverage sections of the rules implementing Executive Order 12549. You may contact the department or agecny to which the proposal is being submitted for assistance in obtaining a copy of those regulations.

6. The prospective primary participant agrees by subitting this proposal that, should the proposed covered transaction be entered into, it shall not knowingly enter into any lower tier covered transaction with a person who is debarred, suspended, declared ineligible, or voluntarily excluded from participation in this covered transaction, unless authorized by the department or agency entering into this transaction.

7. The prospective primary participant further agrees by submitting this proposal that it will include the clause titled "Certificationn Regarding Debarrment, Suspension, Ineligibility and Voluntary Exclusion—Lower Tier Covered Transaction," provided by the department or agency entering into this covered transaction, without modification, in all lower tier covered transactions and in all solicitaions for lower tier covered transactions.

8. A participant in a covered transaction may rely upon a certification of a prospective participant in a lower tier covered transaction that it is not debarred, suspended, ineligible, or voluntarily excluded from the covered transaction, unless it knows that the certification is erroneous. A participant may decide the method and frequency by which it determines the eligibility of its prinicpals. each participant may, but is not required to, check the Nonprocurement List.

9. Nothing contained in the foregoing shall be construed to require establishment of a system of records in order to render in good faith the certification required by this clause.

The knowledge and information of a participant is not required to exceed that which is normally possessed by a prudent person in the ordinary course of business dealings.

10. Except for transactions authorized under paragraph 6 of these instructions, if a participant in a covered transaction knowingly enters into a lower tier covered transaction with a person who is suspended, debarred, ineligible, or voluntarily excluded from participation in this transaction, in addition to other remedies available to the Federal Government, the department or agency may terminate this transaction for cause or default.

CERTIFICATION

(1) The prospective primary participant certifies to the best of its knowledge and belief, that it and its principals:

(a) Are not presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency;

(b) Have not within a three-year period preceding this proposal been convicted of or had a civil judgment rendered against them for commission of fraud or a criminal offense in connection with obtaining, attempting to obtain, or performing a public (Federal, State, or local) transaction or ontract under a public transaction; violation of Federal or State antitrust statutes or commission of embezzlement, theft, forgery, bribery, falsification or destruction of records, making false statements, or receiving stolen property;

(c) Are not presently indicted for or otherwise criminally or civilly charged by a governmental entity (Federal, State, or local) with commission of any of the offensesenumerated in paragraph (1)(b) of this certification; and

(d) Have not within a three-year period preceding this application/proposal had one or more public transactions (Federal, State, or local) terminated for cause or default.

(2) Where the prospective primary participant is unable to certify to any of the statements in this certification, such prospective participant shall attach an explanation to this proposal.

National Science Foundation
Small Business Innovation Research Program

PROJECT SUMMARY

NSF AWARD NO.

NAME OF FIRM	
ADDRESS	
PRINICPAL INVESTIGATOR (NAME AND TITLE)	
TITLE OF PROJECT	
TOPIC TITLE	TOPIC NUMBER AND SUBTOPIC LETTER

PROJECT SUMMARY

Potential Commercial Applications of the Research

KEY WORDS TO IDENTIFY RESEARCH OR TECHNOLOGY (8 MAXIMUM)

NSF Form 1304 (SBIR) (3/94)

Proposal Page No. 2

(SEE INSTRUCTIONS ON REVERSE BEFORE COMPLETING)

SUMMARY PROPOSAL BUDGET

ORGANIZATION	FOR NSF USE ONLY		
	PROPOSAL NO.	DURATION	
		Proposed	Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR	AWARD NO.		

A. SENIOR PERSONNEL: PI/PD and Other Senior Associates (List each separately with title, A.6, show number in brackets)	NSF Funded Person-mos. CAL.		Funds Requested By Proposer	Funds Granted By NSF (If Different)
1.			$	$
2.				
3.				
4.				
5. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)				
6. ( ) TOTAL SENIOR PERSONNEL (1–5)				
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS				
1. ( ) POST DOCTORAL ASSOCIATES				
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)				
3. ( ) GRADUATE STUDENTS				
4. ( ) UNDERGRADUATE STUDENTS				
5. ( ) SECRETARIAL - CLERICAL				
6. ( ) OTHER				
TOTAL SALARIES AND WAGES (A+B)				
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C)				
D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $500.) **(Do not use for Phase I)**				
TOTAL PERMANENT EQUIPMENT				
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS				
2. FOREIGN **(Do not use for Phase I)**				
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ ____ 2. TRAVEL ____ 3. SUBSISTENCE ____ 4. OTHER ____				
( ) TOTAL PARTICIPANT COSTS				
G. OTHER DIRECT COSTS				
1. MATERIALS AND SUPPLIES				
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				
3. CONSULTANT SERVICES				
4. COMPUTER (ADPE) SERVICES				
5. SUBCONTRACTS				
6. OTHER				
TOTAL OTHER DIRECT COSTS				
H. TOTAL DIRECT COSTS (A THROUGH G)				
I. INDIRECT COSTS (SPECIFY)				
TOTAL INDIRECT COSTS				
J. TOTAL DIRECT AND INDIRECT COSTS (H+I)				
K. FEE (If requested; maximum equals 7% of J)				
L. TOTAL COST AND FEE (J + K)			$	$

PI/PD TYPED NAME & SIGNATURE*	DATE	FOR NSF USE ONLY		
		INDIRECT COST RATE VERIFICATION		
CO. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked	Date of Rate Sheet	Initials-DGA

INSTRUCTIONS FOR USE OF SUMMARY PROPOSAL BUDGET (NSF FORM 1030A) (3/94)

1. General

a. Each grant proposal, including requests for supplemental or incremental funding, must contain a Summary Proposal Budget in this format unless a pertinent program guideline specifically provides otherwise.

b. Copies of NSF Form 1030A and instructions should be reproduced locally as NSF will not supply the form.

c. A separate form should be completed for each year of support requested. An additional form showing the cumulative budget for the full term requested should be completed for proposals requesting more than one year's support. Identify each year's request (e.g., "First year_____," or "Cumulative Budget," etc.) in the margin at the top right of the form.

d. Completion of this summary does not eliminate the need to fully document and justify the amounts requested in each category. Such documentation should be provided on additional page(s) immediately following the budget in the proposal and should be identified by line item. The documentation page(s) should be titled "Budget Explanation Page."

e. Revised budgets must be signed and dated by the authorized organizational representative and principal investigator and submitted in at least the original and two copies.

2. Budget Line Items

A full discussion of the budget and the allowability of selected items of cost is contained in the NSF SBIR Solicitation and guidelines. Following is a brief outline of budget documentation requirements by line item. (*NOTE: All documentation or justification required on the line items below should be provided on the Budget Explanation Page.*)

A., B., and C. Salaries, Wages, and Fringe Benefits. On the Budget Explanation Page, list individually all senior personnel who were grouped under A5, the requested person-months to be funded, and rates of pay.

D. Permanent Equipment. Items exceeding $500 and 2 years' useful life are defined as permanent equipment. Fully justify.

E. Travel. Address the type and extent of travel (including consultant travel) and its relation to the project. Itemize by destination and cost and justify travel outside the United States and its possessions, Puerto Rico, and Canada. Include dates of foreign visits or meetings. Fare allowances are limited to round-trip, jet-economy rates.

F. Participant Support Costs. Normally participant support may only be requested for grants supporting conferences, workshops, or symposia.

G. Other Direct Costs.

1. *Materials and Supplies.* Indicate types required and estimate costs.
2. *Publication Costs/Page Charges.* Estimate cost of preparing and publishing project results.
3. *Consultant Services.* Indicate name, daily compensation (limited to $443/day), and estimated days of service, and justify.
4. *Computer Services.* Include justification based on established computer service rates at the proposing company. Purchase of equipment is included under D.
5. *Subcontracts.* Include a completed budget and justify details.
6. *Other.* Itemize and justify. Include computer equipment leasing.

I. Indirect Costs. Specify current rate(s) and base(s). Use current rate(s) negotiated with the cognizant Federal negotiating agency.

APPLICANTS MUST NOT ALTER OR REARRANGE THE COST CATEGORIES AS THEY APPEAR ON THIS FORM, WHICH IS DESIGNED FOR COMPATIBILITY WITH DATA CAPTURE BY NSF'S MANAGEMENT INFORMATION SYSTEM. MISUSE OF THIS FORM MAY RESULT IN RETURN OF PROPOSAL TO APPLICANT.

APPENDIX E

SAMPLE PROPOSAL FROM NSF SBIR SOLICITATION

This proposal, which resulted in a Phase I Award, was submitted under the 1993 NSF SBIR Program Solicitation. The sample proposal is provided solely for general guidance. Note, the proposal format specified in this—the 1994 Solicitation—differs from that in earlier solicitations. The budget has been omitted and social security numbers have been deleted to protect confidentiality.

APPENDIX B

Proposal to the National Science Foundation
COVER PAGE

PROGRAM: SBIR-SMALL BUSINESS INNOVATION RESEARCH		PROGRAM SOLICITATION NO.: NSF 93-18	CLOSING DATE: June 14, 1993

NAME OF SUBMITTING ORGANIZATION (AND LEGAL NAME IF DIFFERENT): Physical Optics Corporation

NAME OF ANY AFFILIATED ORGANIZATIONS (PARENT, SUBSIDIARY, PREDECESSOR):

ADDRESS OF ORGANIZATION (INCLUDE ZIP CODE): 20600 Gramercy Place, Suite 103, Torrance, CA 90501

TITLE OF PROPOSED PROJECT: The Photochemical Generation of Planar Waveguides in Sol-Gel Glasses

REQUESTED AMOUNT	PROPOSED DURATION	PERIOD OF PERFORMANCE
$ 64,992.00	6 months	January 1—June 30

TOPIC NO.	TOPIC TITLE	SUBTOPIC LETTER
20 ·	Electrical and Communication Systems	c

THE ABOVE ORGANIZATION CERTIFIES THAT:	YES	NO
1. It is a small business firm as defined on page 4.	X	
2. A minimum of two-thirds of the research will be performed by this firm in Phase 1.	X	
3. It qualifies as a socially and economically disadvantaged small business as defined on page 4. FOR STATISTICAL PURPOSES ONLY		X
4. It qualifies as a women-owned small business as defined on page 5. FOR STATISTICAL PURPOSES ONLY		X
5. It will permit the government to disclose the title and technical abstract page, plus the name, address and telephone number of the corporate official if the proposal does not result in an award to parties that may be interested in contacting you for further information or possible investment.	X	
6. It will comply with the provisions of the Civil Rights Act of 1964 (P.L. 88-352) and the regulations pursuant thereto.	X	

TO BE COMPLETED BY THE AUTHORIZED ORGANIZATIONAL REPRESENTATIVE. [illegible]

(If answering yes to either, please provide explanation.)	YES	NO
Is the organization delinquent on any Federal debt?		X
Is the organization presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency?		X

[illegible] (U.S. Code, Title 18, Section 1001)

PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR

NAME	SOCIAL SECURITY NUMBER OF PI/PD*	SIGNATURE	DATE
Edgar Mendoza, Ph.D. TELEPHONE NO. (310) 320-3088		[signature]	6/11/93

[illegible] (U.S. Code, Title 18, Section 1001).

COMPANY OFFICIAL (BUSINESS)

NAME	TITLE	SIGNATURE	DATE
Patty Shaw TELEPHONE NO. (310) 320-3088	Chief Financial Officer	Patty Shaw	6-11-93

OTHER INFORMATION

PRESIDENT'S NAME	YEAR FIRM FOUNDED	HAS THIS PROPOSAL BEEN SUBMITTED TO ANOTHER AGENCY?	NUMBER OF EMPLOYEES (TOTAL COMPANY)
Joanna Jannson, Ph.D.	1985	YES ______ NO __Y__	Avg. previous 12 mos. 63; Currently 65

*Submission of social security numbers is voluntary [illegible]

PROPRIETARY NOTICE [illegible]

PROPRIETARY INFORMATION: N/A

NSF FORM 1207A (2/92)

POC #93-217 RD

APPENDIX C

NSF 93-18

National Science Foundation
Small Business Innovation Research Program

PROJECT SUMMARY

NSF AWARD NO.

NAME OF FIRM: Physical Optics Corporation

ADDRESS: Research and Development Division, 20600 Gramercy Place, Suite 103, Torrance, California 90501

PRINCIPAL INVESTIGATORS (NAME AND TITLE): Edgar A. Mendoza, Ph.D., Research Scientist

TITLE OF PROJECT: The Photochemical Generation of Planar Waveguides in Sol-Gel Glasses

TOPIC TITLE	TOPIC NUMBER
Electrical and Communication Systems	20 c

TECHNICAL ABSTRACT (LIMIT TO 200 WORDS)

The commercial realization of the promise of integrated optics technology depends on the establishment of a cost-effective, reliable method of fabricating active and passive waveguiding structures in a thin film format. Physical Optics Corporation (POC) proposes to investigate the development of a novel photolithographic technique that uses commonly available materials, and straightforward processing, to produce both active and passive waveguides in silica-based sol-gel films. The proposed technique offers the possibility of "writing" permanent index variations of up to 0.1 into the silica matrix. Furthermore, the same technique can be used to produce waveguides with nonlinearities in refractive index and transmissivity. During the proposed Phase I effort, POC will prove the practicality of this technique by using it to generate examples of planar waveguides, channel waveguides, and active and passive devices such as splitters, combiners, directional couplers, and Mach-Zender interferometers on a single glass substrate.

KEY WORDS TO IDENTIFY RESEARCH OR TECHNOLOGY (8 MAXIMUM)

Integrated Optics, Photolithography, Optical Interconnects, Optical Switching

POTENTIAL COMMERCIAL APPLICATIONS OF THE RESEARCH

The proposed research would lead to a better understanding of a sol-gel fabrication technique for integrated optics. This technique could be used to reduce cost and improve the reliability of micro-optical elements, including passive and active waveguide devices. Markets for such components include computing, communications, and sensing. Specific applications include VLSI interconnects, miniaturized optical transceivers, and single-chip optical sensors.

NSF Form 1304 (SBIR) (3/91)

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1.0 IDENTIFICATION AND SIGNIFICANCE OF THE PROBLEM OR OPPORTUNITY

The novel technique described in this proposal has the potential to dramatically reduce the cost of fabricating integrated optic devices. Since the initiation of integrated optics research in the late 1960s [1], enormous effort has been directed toward generating miniature integrated optic devices (IODs) for use in next-generation optical interconnects and optical computers. These miniature devices, i.e., channel waveguides, directional beam couplers, beam splitters and combiners, star couplers, fan-in and fan-out couplers, optical modulators, optical switches, and optical circuitry, exhibit extremely desirable characteristics such as reliability of alignment, compactness, and easy fabrication. The problems associated with electronic devices such as electron migration, low fan-out limits, low modulation bandwidth, relatively large power consumption, and electromagnetic interference make passive and active integrated optic devices very promising candidates to replace high-speed and highly parallel distributed processing systems.

Advances in integrated optics for civilian and military applications require the development of materials and technologies that can transmit, guide, modulate, multiplex, demultiplex, receive, and demodulate optical signals. These requirements are crucial for the realization of advanced integrated optic devices that fully employ the potentially wide bandwidth (~THz) of optical signal processing and computing. During the past twenty years, research efforts have focused mainly on $LiNbO_3$ and III-V semiconductor compounds such as GaAs for hybrid and monolithic integration. From systemic and economic points of view, these materials have an array of problems. First, current fabrication techniques for constructing individual waveguide devices are immature from both technology and cost perspectives. For example, to purchase and install thin-film deposition equipment such as molecular beam epitaxy (MBE) or metallorganic chemical vapor deposition (MOCVD) systems requires an investment of up to $2 million. A second problem is that the intrinsic properties of $LiNbO_3$ and III-V compounds prohibit the fabrication of guided wave devices that require high refractive index modulation. For example, high-density diffraction-based wavelength division multiplexing and/or demultiplexing requires a highly multiplexed waveguide grating with an index modulation as high as 0.2. $LiNbO_3$ or III-V based integrated optic devices cannot meet such requirements. Thirdly, the dielectric constants of $LiNbO_3$ and III-V compounds are highly dispersive, which generates large cross-talk between the optical guided waves. Consequently, the modulation bandwidth is limited. In addition, the refractive indices of $LiNbO_3$ and III-IV materials are extremely different from that of silica based glass, the most common, and best, material for optical signal transmission. This incompatibility causes increased reflections, and other problems, when devices made of these materials are coupled to optical fibers. Finally, current low yield rates and high fabrication cost result in IODs that are prohibitively expensive. For example, 8 x 8 cross-bar switches made of Ti-indiffused $LiNbO_3$ by Crystal Technologies, Inc. cost $250k per piece. This is unacceptable for the realization of the optical computer. New methods and subassemblies for fabricating IODs are required to produce price/performance characteristics that are at least a factor of 10 times better than what is currently available.

Physical Optics Corporation (POC) proposes to develop an innovative new technology for the photolithographic fabrication of sol-gel derived integrated optic devices (sol-gel IODs). The fabrication procedure is based on direct photolithographic writing of IODs onto a photoactive sol-gel glass matrix. Sol-gel glasses are made by a two-step process: first a gel film is chemically formed and dried to a porous state, and second the porous film is densified into solid glass at high temperature. In POC's innovative waveguide fabrication technique, an organometallic photosensitizer is "doped" into the porous matrix after the first step. Waveguide patterns are then formed by straightforward photolithographic techniques, and the unexposed sensitizer is removed. The final densification step "locks in" the waveguide patterns, creating a durable, impermeable integrated optic device. Depending on the choice of sensitizer, these waveguide patterns can be passive (simply having a higher index of refraction than the surrounding "host" glass) or active

(possessing optical properties that can be influenced by the application of electric fields). The uncomplicated nature of this process makes this a very promising approach for the fabrication of commercially viable integrated optic devices.

Sol-gel glasses are excellent and inexpensive materials for use in the fabrication of IODs. Sol-gel glasses can be cast into a variety of shapes and forms, they can be coated onto a variety substrates, and they are stable under a wide range of environmental conditions. Sol-gel properties can also be tailored for compatibility with other materials and selected for specific optical properties. Sol-gel IODs can be fabricated either as monoliths or as thin films. Unlike $LiNbO_3$ and III-V based IODs, sol-gel IODs can be coated onto any substrate of interest. Multilayer waveguide coatings offer the advantage of the fabrication of three-dimensional waveguide layers [2]. This is extremely important for a highly parallel, fully interconnected optical signal processing unit. More importantly, waveguide devices such as highly multiplexed gratings and multiple guiding layers, can be easily realized by using sol-gel based IODs.

Phase I research will focus on the fabrication of fundamental integrated optic waveguide structures, such as planar waveguides, passive channel waveguides, waveguide splitters and combiners, waveguide directional couplers, star couplers and Mach-Zehnder interferometers on a single glass substrate, as shown schematically in Figure 1. The aim of the Phase I program is to develop a sol-gel IOD fabrication technology that will allow the expansion of the program to higher order passive and active IOD architectures. At the end of Phase II of the proposed program, POC expects to achieve an IOD technology that could lead to the development of commercial optical interconnects and active devices for optoelectronic, photonic, and sensor markets.

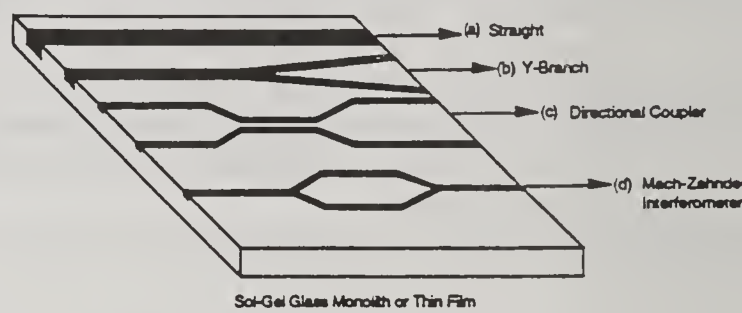

Figure 1
Fundamental integrated optic structures: (a) straight strip waveguide, (b) Y- junction, (c) directional coupler, and (d) Mach-Zehnder interferometer.

2.0 BACKGROUND, TECHNICAL APPROACH, AND ANTICIPATED BENEFITS

2.1 Overall Background

The 20th century has been referred to as "The Information Age." As society becomes more information oriented, the importance of data processing devices continues to rise in both the private and public sectors. The driving force behind this rise is the combination of low-cost processing

systems and greatly enhanced data generation capabilities. To keep up with the information processing demands, devices capable of handling vast amounts of information are required. The increasing importance of integrated optics and optoelectronics is reflected by the intensive research being done in many laboratories worldwide [3]. The major motivation that drives this research and development is the unique capability of light waves to transmit and process information with very high bandwidths (THz). One of the most prominent examples of the success of optical technology is the development of optical fibers, which play a major role in telecommunications.

During the past two decades, materials developments have resulted in the realization of novel integrated optics and optoelectronics devices and concepts. Materials such as glass, $LiNbO_3$, III-V semiconductors, and polymers have resulted in the development of prototype IODs for advanced communications, signal processing, and sensor systems. Integrated optic signal processing systems have many advantages over the classic VLSI electronic systems. Nevertheless, usable integrated optic systems await the solution to a variety of problems. The original proposal for integrated optic components made by Miller in 1969 does not differ much from today's designs. The question of why these components are still under development and not commercially available in large quantities is quite easy to answer: the technological processes required to mass produce integrated optic devices are not yet economically feasible.

2.2 Technical Approach

To overcome the disadvantages and processing limitations of current IOD technologies, POC proposes a new approach: using photochemically active sol-gel glasses for the photolithographic generation of IODs on a glass substrate. In Phase I of this proposed program, POC will demonstrate the ability to process optically sensitive sol-gel silica monoliths and thin films on a suitable substrate such as glass or silicon. This process will include the synthesis of the sol-gel glass precursor solution, growth of the sol-gel monolith and coating of the sol-gel thin film (spin or dip coating), impregnation of photoactive organometallic compound into the sol-gel glass matrix, light exposure of photoactive sol-gel glass, vacuum removal of unexposed organometallic reagent, and thermal treatment (conversion of exposed organometallic reagent to a metal oxide layer and densification of the sol-gel glass matrix). The basic structure of POC's proposed sol-gel IODs is illustrated in Figure 2. Phase II will be devoted to developing a practical technology for the photogeneration of active IODs, i.e., optical waveguide modulators and switches using novel photoactive organometallic compounds in a glass matrix.

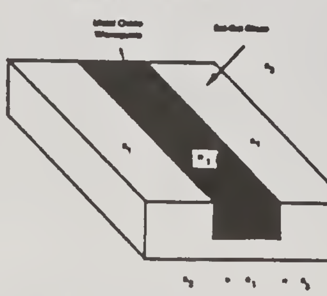

Figure 2
Basic structure of sol-gel channel waveguides.

The basic components of IODs are dielectric films used to guide electromagnetic energy of wavelengths from 0.2 to 10 µm. Channel waveguides made by the photolithographic deposition of metal oxides onto sol-gel glasses are ideal for the fabrication of low loss IODs [4]. Both passive and active devices can be fabricated by the deposition of a suitable metal oxide. For example, the photodeposition of SnO_2 from an organometallic tin precursor onto porous silicate glasses produces changes in the index of the glass on the order of 0.1 to 0.001. This property allows a He-Ne laser beam to be guided through a 1.0 µm channel waveguide with a curvature of 1.0 inch, as shown in Figure 3. Similarly, optomagnetic strip waveguides can be made by the photodeposition of partially magnetic Fe_2O_3 particles [5]. The advantage of the photodeposition technique is that it offers the possibility of integrating multicomponent devices on a single glass substrate.

Figure 3
Photo of a He-Ne laser launched onto a 10 µm channel waveguide photodeposited onto porous Vycor glass.

Compared to ion-exchange in glasses, $LiNbO_3$, and III-V integrated optic technologies, POC's proposed sol-gel IODs offer a reproducible, low-cost fabrication approach to IODs on a glass matrix. The basic features of the sol-gel IODs are summarized in Table 1 and are compared with $LiNbO_3$ and III-V based IODs.

Table 1 Features of Sol-Gel Integrated Optic Devices

Features	Material for Integrated Optic Devices (Sol-Gel Glasses)	(LiNbO3 Crystals)	(GaAs Semiconductor)
Planar Waveguide	Yes	Yes	Yes
Channel Waveguide	Yes	Yes	Yes
Electro-optic Modulator	Yes	Yes	Yes
Waveguide Propagation Loss	< 0.01 dB/cm	< 0.1 dB/cm	< 1 dB/cm
IOD Dimensions	Unlimited [a]	Limited [a]	Limited [a]
Implementation on Other Substrates	Easy [b]	Difficult [c]	Difficult [c]
Multiple-Guiding Layer on Single Substrate	Yes [d]	No	No
Channel Waveguide Packaging Density (channels / cm)	Very High	High	High
Waveguide Lens	Yes	Yes	Yes
Dielectric Constant Dispersion	Low	High	High
Potential Modulation Speed	> 100 GHz	~ 30 GHz	~ 30 GHz
Fabrication Cost	Low	High	High

a) Sol-gel glass can be coated onto any large substrate while $LiNbO_3$ and GaAs based IOD's are limited by the crystal dimension
b) Thin-film coating (sol-gel) vs. epitaxy (others)
c) $LiNbO_3$ and GaAs are thick film devices which are difficult to transfer to other substrates
d) Up to 1000 channels/cm on doped sol-gel glass [6], 500 channels/cm on GaAs [7], and 333 channels/cm on $LiNbO_3$ [8]

It is clear from Table 1 that all of the IODs made on $LiNbO_3$ and GaAs substrates can be easily replaced by sol-gel IODs. Because of the outstanding features of sol-gel IODs, we expect performance characteristics a factor of 10 times better than those of existing IODs based on $LiNbO_3$ and GaAs technologies.

2.3 Innovativeness and Originality of the Proposed Research

Photolithographic definition of photochemically active sol-gel films offers a completely new approach to the fabrication of integrated optical waveguides and devices. In contrast to older methods of fabricating waveguide structures, no epitaxially grown materials, salt-bath diffusion, etching, vapor phase deposition, or other low-reliability, high-cost techniques are used: the proposed approach relies on straightforward techniques such as spin-coating, air-drying, solution-phase doping, photolithography, and vacuum drying.

The proposed research effort will be carried out by a principal investigator whose Ph.D. originated the sol-gel photochemical approach to waveguide fabrication during his Ph.D. dissertation research. The research proposed here is an entirely original effort aimed at initiating the study of the commercial viability of this class of devices. Because of the great potential market for cost-effective, reliable IODs, POC believes that the successful completion of Phase II of the proposed project will virtually guarantee non-federal follow-on investment for Phase III product development.

2.4 Anticipated Results and Commercial Applications of Phases I and II

All the building blocks needed for the development of integrated optic signal processing systems (see Figure 1) will be demonstrated in Phase I, and the development of a working low-level

optical processor will be realized in Phase II. Commercial applications include 2-D and 3-D optical interconnects, all optical modulators and switches, high-performance optical computers, intracomputer interconnects, and fiber optic physical and chemical sensors.

3.0 PHASE I RESEARCH OBJECTIVES

The basic goal of the Phase I effort is to demonstrate the ability to photolithographically define optical waveguides in photoactive sol-gel glasses. The following are the technical objectives for Phase I.

1. Experimentally determine the optimum sol-gel processing conditions for the fabrication of photoactive glasses.
2. Demonstrate the growth of stable photoactive sol-gel monoliths and thin-film coatings on suitable substrates, such as glass and silicon. This objective includes the optimization of drying, coating, and thermal treatment.
3. Determine the best technique for the pattern generation of channel waveguides. This objective includes a comparative evaluation of contact printing, microlithography, and holographic writing.
4. Demonstrate sol-gel-derived fundamental IOD structures, as shown in Figure 1.

4.0 PHASE I RESEARCH PLAN

4.1 Formation of Sol-Gel-Derived Waveguides

The formation of high quality IODs relies primarily on the availability of waveguiding materials. The ability to generate a gradient index on a glass substrate allows the guidance of a laser beam. However, to perform the functions required for passive IODs demands the formation of highly resolved gradient index patterns. Application of gradient refractive indices within glass matrices [10] and sol-gel glass matrices [11] has been recognized for several years. Sol-gel glasses impregnated with photosensitive organometallic compounds exhibit optical changes when exposed to light. Optical changes in both transmission and reflection can be induced and are permanent after heat treatment of the sol-gel glass matrix. Using combinations of elements similar to those described in the following sections offers a means of fabricating optical circuits of both passive and active IODs.

4.1.1 Requirements for the Photo-Generation of Sol-Gel-Derived Waveguides

The photochemical deposition of a metal oxide onto sol-gel glass to achieve a gradient refractive index waveguide structure depends on three factors:

(1) The sol-gel glass matrix must be optically transparent in the region of optical absorption of the photoactive organometallic compound. Visible and UV photosensitivity allows photolysis of the adsorbed organometallic compound through the bulk of the glass matrix rather than on the outer surface. Since the transparency of sol-gel glasses can be chemically tailored during processing to transmit wavelengths from 180 nm to 20 μm, this requirement is easily established. It is important to note that light guiding occurs within the bulk of the medium, consequently, photodeposition within the bulk is essential. Of course, it is also desirable that the quantum yield of the photochemical reaction on the glass substrate be high, 1.0 if possible.

(2) The photochemical reaction must irreversibly bind the adsorbate to the sol-gel glass matrix. This requirement is essential to maintain the resolution of the photoinduced pattern and to prevent desorption of the adsorbate during subsequent thermal treatment.

(3) The sol-gel glass substrate must exhibit thermal stability and retain volatility. Volatility is essential, since a key to obtaining a significant gradient index is the ability to remove the unphotolyzed organometallic material. If the unphotolyzed compound decomposes during thermal treatment, the gradient index that was generated photochemically will be destroyed.

4.1.2 Sol-Gel Glass Processing

The sol-gel process is a relatively new approach to the preparation of oxide glasses. Starting from molecular precursors, an oxide network is obtained via inorganic polymerization reactions. These reactions occur in solutions, and the term "sol-gel processing" is often used to describe the synthesis of inorganic oxides by wet chemistry methods. This process offers several advantages: (1) homogeneous multicomponent glasses can be easily obtained by mixing the molecular precursor solutions; (2) glasses produced using organometallic precursors have higher purity and lower processing temperatures than comparable glasses produced by conventional melting; and (3) the rheological properties of sols or gels allow the formation of fibers, films, monoliths, or composites by techniques such as fiber drawing, spinning, dipping, casting, and impregnation.

A typical sol-gel process involves a solution of metal alkoxide, water, and a suitable solvent, e.g., ethanol, that undergoes a sol-to-gel transition to form a gel, which is then dried to form a porous hydrated glass. A common example of such a system is the use of a mixture of tetraethylorthosilicate (TEOS), water, and ethanol to produce fused silica glass. Other examples include aluminumtert-butoxide [Al(OBu)3] for alumina gels and tetraorthoethyltitanate (TET) for titania gels. Despite an incomplete understanding of the sol-gel transition, the sol-gel process has been used in numerous applications.

The chemistry of the sol-gel process is based on the hydroxylation and condensation reactions of organometallic molecular precursors. These reactions have been studied extensively in the case of silica [12]; however, much less data is available for other metal oxide precursors. The most versatile precursors for the sol-gel synthesis of oxides are undoubtedly metal alkoxides, which are very reactive towards nucleophilic reagents such as water. Hydrolysis occurs when a metal alkoxide and water are mixed in a mutual solvent, usually an alcohol. Empirical miscibility formulations for TEOS-water-ethanol solutions at room temperature are plotted on the triangular phase diagram of Figure 4 in mole percent. Sol-gel matrices for IODs can be divided into spinnable, coatable, and castable solutions. Solutions are spinnable with less than 40 mole percent water, are coatable between 40 and 70 mole percent water, and only those solutions with more than 70 mole percent water are castable. The complete history of the preform is dominated by the TEOS:water ratio.

Figure 4
Triangular construction for the TEOS-ethanol-water sol-gel system with compositions plotted in mole percent.

Casting the sol-gel glasses will be accomplished by a two step process: (1) preparation of the sol-gel solution and (2) casting the solution in a premolded container. The preparation procedure for the coating solution is shown schematically in Figure 5. The SiO_2 alkoxide system will be chosen for the Phase I study. A solution of tetraethylorthosilicate in ethanol will be partially hydrolyzed with water containing approximately 1% HCl at room temperature for 60 minutes. Casting the solution is accomplished by pouring the partially hydrolyzed solution into a casting mold followed by gelling the solution for 1 to 2 weeks. After gelling, the disk is heat treated in a very rigorous heating cycle ranging from 25° to 750 °C. At the end of the heating cycle, the material is an amorphous porous silica.

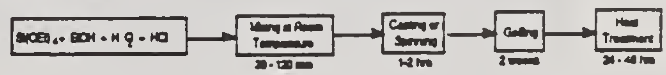

Figure 5
Preparation procedure for TEOS monoliths and films.

4.1.3 Photosensitive Organometallic Compounds

The proposed photolithographic generation of IODs in sol-gel glasses is based on the photochemical binding of an organometallic reagent onto the glass substrate followed by thermal conversion of the photodeposited organometallic compound to metal oxide thus raising the local index of refraction. The criteria in the selection of the organometallic reagents are:

1. The compound must be photoactive.
2. The compound must exhibit volatility.
3. The compound must exhibit thermal stability.
4. The remaining metal oxide must have an index of refraction different from that of silica.

Photoactivity is a critical requirement to generate a GRIN pattern on the glass matrix, since the compound must irreversibly bind to the glass matrix during photolysis. Volatility is required to remove the unphotolyzed compound from the glass matrix before the thermal treatment. Thermal stability is required, since easily pyrolyzed compounds will decompose on the glass matrix, hence destroying the photo-induced pattern.

There are several photoactive organometallic compounds that satisfy these criteria. In this proposal we will focus onto three families of compounds: (1) Group IV organometallics, e.g., tin and lead alkyl halides; (2) compounds based on Group VIII transition metals, e.g., iron and ruthenium carbonyls; and (3) compounds based on Group IV and VI transition metals such as titanium and chromium. The Group IV organometallics will be the first compounds studied since they form transparent oxides (SnO_2 and PbO_2) upon photolysis [13]. In particular, we will investigate trimethyltiniodide and trimethylleadiodide, since the M—I bond (M = Sn; or Pb) is highly photosensitive and the compounds are volatile at room temperature. Other compounds to be investigated will be ironpentacarbonyl, ruthenium hexacarbonyl, and titaniumpentadienyldichloride.

4.1.4 Photo-Imaging of Sol-Gel IODs

Photo-imaging of sol-gel IODs involves the direct writing of a pattern onto a photosensitive sol-gel glass plate (see Figure 6). The steps involved in this process are: (1) fabrication of a porous sol-gel monolith or film; (2) impregnation of the porous sol-gel with a photosensitive organometallic

material; (3) writing the desired pattern onto the photosensitive porous sol-gel; and (4) drying and heat treatment to obtain a nonporous glass. The procedure for fabricating the sol-gel monoliths and films is the same as the one already described, with the exception that the dried gels will be only partially heated (650°C). This is a necessary step to obtain a porous sol-gel matrix. Impregnation of the organometallic compound onto the porous matrix will be done by chemical vapor deposition methods. During the Phase I program, several photosensitive organometallic compounds will be investigated. When the compound has been adsorbed onto the sol-gel matrix, contact printing, microlithography, or holographic writing will proceed by exposing the photosensitive sol-gel matrix to laser light. Once the waveguide pattern has been written, the unexposed organometallic reagent will be removed by placing the sol-gel plate in a vacuum chamber for several hours. The final stage of the process is to continue the heat treatment of the sol-gel glass to obtain a nonporous matrix.

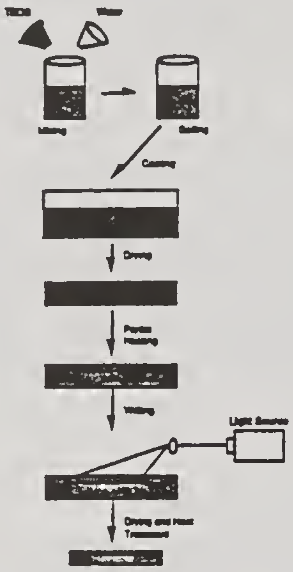

Figure 6
Photo-imaging of sol-gel IODs.

4.1.5 Planar and Channel Waveguides

The formation of planar and channel waveguides is achieved by exposing the photoactive sol-gel glass monolith or thin film to light through a chrome mask, by directly writing on the surface of the glass with a focused laser beam, or by exposing it to a holographic image. The technique results in the photodeposition of a metal oxide into the glass substrate. The deposited metal oxide acts as a gradient index glass modifier after the thermal treatment of the glass substrate. The width of the channel waveguide is controlled by the resolution of the photomask. Typical widths obtained from

contact printing range from 100 mm to 1 µm. The thickness of the planar or channel waveguide is controlled by: (a) the concentration of the organometallic precursor on the glass substrate before it is exposed to light; (b) the exposure time of the excitation source; and (c) in the case of thin films, the thickness of the film.

The gradient index profile of a channel waveguide of a sol-gel glass substrate depends on various parameters. The purity of the host glass, the nature and concentration of the photodeposited metal oxide, the diffusion of the metal oxide onto the glass substrate, and the time and power of the excitation source, all affect the index profile. Several techniques allow the direct measurement of the index profile in waveguides, including interferometry, reflectivity, and the WKB method, which relies on mode index data. Interferometry is by far the most accurate technique. The gradient index profile can also be measured by indirect methods. For instance, it has been demonstrated that the metal oxide concentration profile gives a gradient index profile [7]. POC will employ all of these techniques to study the waveguides fabricated during this project.

POC has previously demonstrated a graded index, high quality (loss < 0.1 dB/cm) polymer planar waveguide on an array of different substrates. A polymer planar waveguide on a GaAs substrate is shown in Figure 7(a). A channel waveguide on photo-lime gel was formed by a laser-induced cross-linking process. A photomask containing the channel waveguide and waveguide arrays was used to transfer the pattern to the polymer thin film through conventional lithography. Figure 7(b) illustrates a linear polymer-based channel waveguide array with a packaging density of 1250 channel/cm at 632.8 and 1310.0 nm. The proposed sol-gel technology has many of the positive features of polymer waveguides (ease of fabrication, versatility), with one important advantage: after densification, the sol-gel glass waveguides are virtually impervious and are physically quite rugged.

632.8 nm 1310.0 nm

(a) (b)

Figure 7
(a) Polymer planar waveguide on GaAs substrate; (b) single-mode polymer-based channel waveguide array with 1250 channels/cm packaging density.

4.2 Project Tasks

The objectives of the proposed project will be accomplished through the performance of the following tasks:

Task 1 *Establish and Define Waveguide Requirements for IOD Structures*
The waveguide geometries for straight and curved structures suitable for the fabrication of integrated optic devices will be theoretically determined. In particular, requirements such as the waveguide design, waveguide refractive index, and waveguide dimensions for multimode and single-mode devices will be established.

Task 2 *Fabricate Sol-Gel Glass Monoliths and Thin Films*
Sol-gel monoliths and thick films will be fabricated from Si-alkoxide precursors. Different chemical compositions will be analyzed to obtain homogeneous films and disks free of cracks, bubbles, and inclusions. The optimized monolith or film formulations will be used during Task 4 to fabricate integrated optic structures in the sol-gel matrix.

Task 3 *Evaluate Organometallic Reagents*
An in depth investigation of photoactive organometallic reagents will be performed at the beginning of this task. From this investigation, potential organometallic reagents will be purchased and their photochemical behavior will be characterized. Photochemical studies will investigate the efficiency of the photochemical reactions. At the end of this task, the compounds for the fabrication of IODs will be chosen.

Task 4 *Fabricate Sol-Gel Integrated Optic Structures*
Initially, contact printing will be used as the photoimaging technique to fabricate the basic integrated optic structures (see Figure 1) onto the sol-gel glasses. Once the correct excitation wavelength and exposure levels have been investigated, microlithography and holographic imaging will proceed. The processing thermal cycle of the exposed glasses to obtain non-porous optical glasses will be established.

Task 5 *Evaluate Sol-Gel Integrated Optic Structures*
The photoinduced waveguide structures will be evaluated for their optical characteristics, i.e., attenuation, bending losses, coupling efficiency, and cross-talk.

Task 6 *Prepare the Final Report and Phase II Proposal*
A comprehensive final report will be written to describe the experimental procedures and results in detail.

4.3 Performance Schedule

The tasks listed in Section 4.1 will be performed in accordance with the schedule shown in Figure 7.

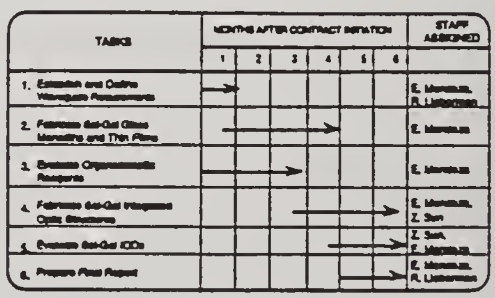

Figure 7
Performance schedule.

5.0 COMMERCIAL POTENTIAL AND FOLLOW-ON FUNDING COMMITMENTS

5.1 Brief Description of the Company

Physical Optics Corporation (POC) was founded in 1985 with the mission of developing new technologies and products for emerging photonic markets. Drawing upon a strong team of scientists and engineers from diverse technical backgrounds, POC has established a unique blend of capabilities. Today, POC is among the leaders in the photonic industry, based on its new technologies in holography, high-speed multi-media communication, and photonic instrumentation. In 1992 POC generated $6.3 million sales from a combination of government contracts, and sales of a variety of commercial optical components and photonic systems. In 1991, Inc. magazine listed POC among the fastest growing private companies in America.

At present, POC has 65 employees, including 18 with Ph.D. degrees, who conduct research, development, engineering, and production activities in state-of-the-art facilities which rival those of major United States corporations. To date, POC has completed over 100 government and commercial development contracts, which has brought the company to its leadership position in many areas of photonics. POC technologies and products are protected by 20 granted or pending patents, and 50 patent disclosures in various areas of optics and photonics.

From its inception, POC has been an active participant in the SBIR program. To accelerate its product commercialization, POC has raised $2.7 million in venture capital financing and has established banking credit lines of over $2 million. Specifically, as a result of prior SBIR contracts, POC has introduced to the marketplace five families of products. They are: (1) Fiber Optic Wavelength Division Multiplexers (HoloMux™), (2) Fiber Optic Data Links (HoloLinks™), (3) Holographic Filters, (4) Holographic Optical Elements (HOEs), and (5) High-Gain Diffusers.

5.2 Commercial Applications

Integrated optic subsystems, combined with VLSI electronic and optoelectronic systems have numerous potential applications in data acquisition, information processing, and optical computing systems. For example, the use of passive integrated optic "chips" to connect sources, detectors, and fiber leads in a single, rugged, module, could create tremendous cost savings in the fabrication

of fiber optic transceivers if the passive IOD could be made using the proposed sol-gel based technology. Such a cost savings is seen as absolutely essential in the implementation of the "fiber-to-the-home" networking strategies that are envisioned for the next decade. Thus, one direct commercial application of the proposed technology would be in the fabrication of critical components for low-cost fiber optic links.

POC would focus on strategic partnerships with existing telecommunications hardware suppliers to bring products of this type to market.

Active integrated optic waveguides also have a very wide range of potential applications. The proposed sol-gel technique could be used to dramatically lower the cost of such devices, bringing them into the reach of designers of systems as small as personal computers and private branch exchange (PBX) communications equipment. For example, the availability of low-cost integrated optical switching modules would permit their use in local area network applications, thus greatly enhancing the performance of optical networks without significantly increasing price.

The two potential applications of sol-gel integrated optical devices described above together represent an aggregate market of over $100M over the next ten years. Many other commercial products, including high speed optical interconnections for chip-level signal processing, micro-optical chemical and physical sensors, guided wave modulators, tuning stages for DFB lasers, and rare-earth doped planar ring resonators for amplifier applications, could potentially be developed using the proposed technology. The choice of entry markets for sol-gel waveguide devices will be made in parallel with the performance of the Phase II research and development effort, but the commercial impact of the proposed technology on optical communications, sensing, and data processing is potentially very large.

5.3 Competitive Products

High performance III-V semiconductor and $LiNbO_3$ photonic optoelectronic devices have been realized and demonstrated using advanced materials technology. The devices have been manufactured commercially for use in trunk telecommunications, local area networks, and cable TV distribution. However, more advanced optoelectronic devices are needed for incorporation into future communications systems, including the expected "information super highways" currently under development in Europe, Japan, and the United States. This imposes stringent requirements on performance, complexity, and cost. System optimization is currently driven by the need to minimize device and interconnection costs. The solution to this problem lies in the realization of new materials and techniques capable of producing large numbers of devices at a relatively low cost.

5.4 Advantages of the Proposed Approach Over Existing Technology

The major advantages are summarized in Table 1. They include low propagation loss, large interconnection distances well beyond $LiNbO_3$- and GaAs-based photonic devices, implementation on any substrate of interest, 3-D vertical integration, and extremely low fabrication cost. All of these advantages have been demonstrated for the proposed material system.

In our approach, sol-gel photoactive glasses are used to fabricate IODs because:

(1) Glass is the most ideal material for the fabrication of IODs. It has the best material properties for light propagation and attenuation, it is the most compatible material for coupling to optical fibers, and it is the material of choice in telecommunication applications.

(2) Sol-gel glass processing is a low-cost approach to the fabrication of high quality optical glasses. Sol-gels are castable and can be deposited onto a variety of

substrates, their optical properties can be tailored to transmit light from the deep UV (180 nm) to the far IR (20 μm).

(3) Like electronic VLSI technology, the sol-gel IODs are either photolithographically and/or holographically patterned on an optical glass matrix. These options give the advantage of using technology in which POC is quite experienced.

(4) The proposed sol-gel IODs represent the only glass material that can integrate all the active and passive waveguide devices, i.e., planar waveguides, channel waveguides, multiplexed holograms for fan-out and fan-in, 3-D packaging for high density optical interconnects, waveguide lenses, optical modulators, and optical switches, monolithically on any substrate of choice (due to its GRIN characteristics). Other issues such as low propagation loss (< 0.01 dB/cm), high channel waveguide packaging (1000 channels/cm), and low fabrication cost are all critical factors for the development of high performance signal processing systems.

5.5 Transfer from Research to Market

Physical Optics Corporation is proud of its record in commercializing the technologies evolving out of SBIR projects. To date, the company has:

- Attracted commercial and government non-SBIR follow-on funding in the amount of $11.3 million. Of this amount, $7.8 million was used as follow-on funding for Phase II programs completed by the end of 1992. The remaining $3.5 million is being used in support of more recent Phase II projects.

- Introduced into the commercial marketplace five families of products in the areas of holography, fiber optics and photonics (see Section 5.1).

- Accomplished commercial sales in the amount of $3,200,000.

POC's successful record of commercializing SBIR technologies has been recognized by the Small Business Administration. In its 9th Annual Report to Congress (1992), the SBA selected eight companies nation-wide for highlighting their SBIR commercialization accomplishments. POC feels honored to be among those so highlighted (see page 22 of the Report).

POC will apply the same strategy that proved so successful in the past, to secure follow-on funding for, and eventual commercialization of, the proposed sol-gel integrated optical devices.

5.6 Prior NSF/SBIR Grant Support

Since January of 1990, NSF has granted POC a total of 13 SBIR Phase I and two Phase II awards. In addition, three Phase II NSF/SBIR proposals are pending response. No NSF/SBIR Phase II project has yet been completed. However, follow-on funding commitments and commercialization opportunities are being vigorously pursued on all active projects, using the same strategies that proved successful in commercializing the results of completed SBIR Phase II projects (see Section 5.5).

6.0 RELATED RESEARCH

6.1 Pertinent Recent Research by Others

Different technologies have been employed to achieve waveguides in various materials. The devices made in these materials can be divided into four categories: passive, electro-optic, optoelectronic, and all optical. Glass has been the most popular material to make passive, and all optical devices. A number of different technologies have been employed to make glass waveguides: sputtering [14], chemical vapor deposition [15], ion implantation [16], ion exchange [17], photolithography [2], and only recently sol-gel processing [2,18]. Although ion exchange has been the most popular technique for the fabrication of integrated optic devices in glass, it still remains an expensive elaborate process with mass production limitations.

The POC approach presented in this proposal is unique because its success provides compatibility with electronic VLSI technology. Therefore, cost effectiveness and mass production is expected. Moreover, solid state devices, e.g., lasers and detectors, can be integrated in one common substrate such as GaAs beneath the photolithographed sol-gel waveguides.

6.2 Related Research by POC Personnel and Consultants

Dr. Mendoza, the principal investigator, has very substantial experience in the field of sol-gel and ceramic materials processing. In particular he has focused his research effort on the development of techniques for the generation of gradient refractive indices in glasses. Dr. Mendoza is the originator of the sol-gel/photochemical technique of fabricating optical waveguides and has published and presented several scientific reports on the feasibility of this approach. Dr. Mendoza also has experience in the mechanistic interpretation of photochemical and photophysical events in the solid state. His current research deals with the development of fiber optic and integrated optic chemical and environmental sensors using glass as the sensor support medium.

POC was engaged in an earlier project to develop planar optical waveguides based on polymer coatings, as detailed in Section 4.1.5 (see Figure 7). The experience gained in this project will help to insure the success of the lithographic aspects of the currently proposed project.

6.3 Related Projects at POC, Past and Ongoing

To illustrate significant activities at POC directly related to this proposal, here are some examples of relevant projects:

DARPA *VLSI OPTICAL INTERCONNECTS BASED ON MULTIPLEX BRAGG PLANAR HOLOGRAPHY*
CONTRACT NO.: DAAH01-87-C-0822
AMOUNT: $540,000
This project demonstrated a multi-mode planar hologram technology that serves as an optical interconnect system for VLSI devices in interchip and inter-processor applications.

SDIO *POLYMER GELATIN MICROSTRUCTURE WAVEGUIDES IN CONJUNCTION WITH HOE FOR ELECTRONICS ON VLSI OPTICAL INTERCONNECTS*
CONTRACT NOs.: DASG60-89-C-0053__DASG60-90-C-0018
AMOUNT: $571,944
In Phase I of this program, a new polymer graded-index waveguide was investigated for optoelectronic device and system applications. The polymer can form guiding layers on any smooth surface including conductors, semiconductors, and insulators. Local sensitization of the polymer waveguide allows integration of single and multiplexed holograms in the selected area. A 50-channel, single-mode Wavelength Division Multiplexer (WDM) was built in Phase II.

NSF *POLYMER GELATIN WAVEGUIDE MODULATOR--Phases I and II*
CONTRACT NOs.: ISI-8961123__ISI-9100146
AMOUNT: $299,981
A new $c^{(2)}$ polymer has been developed that has a g_{33} three times larger than $LiNbO_3$. A traveling wave modulator with a modulation bandwidth of 100 GHz will be demonstrated in Phase II of this program. The newly developed $c^{(2)}$ polymer has a graded index (GRIN) that can be implemented on any substrate of interest.

SDIO *LOW THRESHOLD ALL-OPTICAL CROSSBAR SWITCH ON GaAs-GaAlAs CHANNEL WAVEGUIDE ARRAY*
CONTRACT NOs.: F49620-90-C-0068__F49620-92-C-0047
AMOUNT: $545,878
A low threshold 10 x 10 all-optical crossbar switch is under investigation. Unlike conventional all-optical devices, where a high power laser is needed to generate the required optical-optical interaction, the GaAs channel waveguide and waveguide array need only a 1 mW laser (for example, 670 nm laser diode) to activate the modulation. As a result, system compactness and resulting cost effectiveness are expected. Switching speeds as fast as subpicosecond are feasible by H^+ion implantation. In this program, a fully packaged 10 x 10 all-optical crossbar switching device, including a laser diode array, GRIN lens array, activation window, and 10 x 10 GaAs channel waveguide array will be demonstrated.

7.0 PRINCIPAL INVESTIGATOR AND SENIOR PERSONNEL--ELIGIBILITY AND QUALIFICATIONS

7.1 Principal Investigator

This research will be performed by a POC scientific team with a successful track record in developing technologies under numerous grants and contracts from various federal agencies (DOD, DOE, DOT, NASA, NIH and NSF). Dr. Edgar Mendoza will serve as the Principal Investigator. His resume follows.

Edgar A. Mendoza, Research Scientist, received his B.S. in chemistry from Buffalo State College, NY. He attended the City University of New York, where he received M.S. and Ph.D. degrees in Physical Chemistry, with emphasis in photochemical reactions in the solid state. While earning his Ph.D., he developed a novel photolithographic technique via the photodeposition of organometallic reagents in porous glasses and sol-gel glasses. He then used this technique for the deposition of integrated optic circuits in glasses, photoimaging of optic and magnetic sensitive refractive index gradients, formation of microscopic regions of porosity within planar waveguide structures and the impregnation of these structures with chemical and optical sensitive materials.

His work has included the fabrication of planar waveguide chemical sensors, monolithic and thin-film sol-gel glasses doped with laser dyes, and nonlinear optical polymers for all optical switching applications, and thin-film micro-lasers. After finishing his doctoral thesis, Dr. Mendoza joined the Center for Ceramic Research at Rutgers University as a post-doctoral fellow. At Rutgers he worked at the fracture mechanics solid-state laboratory where he developed a micro-spectroscopic technique (Raman and FTIR) for the in-situ measurement of residual stresses in fiber reinforced ceramic matrix composites. Dr. Mendoza has published over 20 publications and has presented his worked in numerous technical conferences in the fields of solid-state chemistry, materials science, and integrated optics.

Directly Related Publications by the Principal Investigator, Edgar Mendoza

1. E. A. Mendoza, D. L. Morse, and H. D. Gafney, "The Photochemical Deposition of Non-Linear Optical Materials into Porous Glass," Nonlinear Optical Materials, CRC Press: London, Eds. Kuhn, H.; Robillard, J., 179-190 (1992).
2. J. Heo, D. C. Lam, E. A. Mendoza, D. A. Hensley, and G. H. Siegel, "Spectroscopic Analysis on the Structure and Properties of Alkali Tellurite Glasses," J. Am. Cerm. Soc. (Feb. 1992).
3. E. A. Mendoza, and H. D. Gafney, "Photolithographic Imaging of Planar Optical Waveguides and Integrated Optic Devices onto Porous Silicate Glasses and Silica Sol-Gels," Proceeding of the MRS Society, Symposium in Optical Waveguide Materials, Boston, MA, Dec 3-7 (1991).
4. E. A. Mendoza and H. D. Gafney, "Photolithographic Processing of Integrated Optic Devices in Glasses," Proceeding of the SPIE Society, Symposium in Integrated Optical Circuits, Boston, MA, Sept. 12 (1991).
5. E. A. Mendoza, E. G. Wolkow, D. Sunil, J. Sokolov, M. H. Rafailovich, M. den Boer, H. D. Gafney, and Langmuir, "Photoimaging on Porous Vycor Glass and TMOS Xerogels," 7, 3046-3051 (1991).
6. E. A. Mendoza, E. Wolkow, H. D. Gafney, D. Sunyl; M. H. Rafailovitch, and J. Sokolov, "Small Angle X-Ray Scattering (SAXS) from Metal Impregnated Porous Vycor Glass and Silica Gels," Appl. Phys. Lett., 57, 209 (1990).
7. E. A. Mendoza, D. L. Morse, H. D. Gafney, "The Photochemical Generation of Integrated Optic Devices on Glass, I" Proceedings of the MRS Society, Boston, November (1990).
8. E. A. Mendoza, D. L. Morse, H. D. Gafney, "The Photochemical Generation of Gradient Indices on Glass, II," Proceedings of the SPIE Society, Symposium on Laser Science and Optics Applications, Boston, November (1990).
9. E. A. Mendoza, E. Wolkow, P. Wong, and H. D. Gafney, "Highly Resolved Gradient Patterns in Glass-Gels by Means of Chemical Vapor Deposition," Proceeding of the Material Research Society, Boston, MA, November 4-9 (1989).
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In his work, the Principal Investigator will be supported by a team of POC scientists that will include Robert Lieberman and Zongjian Sun. Their resumes follow.

Robert A. Lieberman, Director, Advanced Fiber Optics, will provide technical oversight for the project. Dr. Lieberman received both his B.S. and M.S. in Physics at Rensselaer Polytechnic Institute. From the University of Michigan, he received a Ph.D. in physics with an emphasis on solid-state physics and biophysics, investigating active site configurations in copper proteins using electron spin resonance. After receiving his doctorate, Dr. Lieberman joined AT&T Bell Laboratories where he was a member of the technical staff for ten years. From 1981 to 1984,

in the Semiconductor Device Development Division, he studied magnetooptic garnets and their application to bubble memory devices and helped to develop high power high frequency gallium arsenide field effect transistors. In 1984, he joined the Molecular Biophysics Department and, funded by the Medical Venture organization within Bell Labs, initiated a project developing fiber optic biosensors. From 1986 through 1991, Dr. Lieberman worked in the Optical Fiber Research Department, where he was the principal investigator for research on fiber optic sensors. In this capacity, he successfully developed several novel fiber optic chemical sensors, pressure sensors, magnetic field sensors, and temperature sensors. Dr. Lieberman came to POC in 1991 as the director of POC's Advanced Fiber Optic Laboratory. Since joining POC, he has been the principal investigator on projects for the National Science Foundation, the U.S. Air Force, the U.S. Navy, the New York Gas Group, and the U.S. Department of Energy. These projects are aimed at developing novel fiber optic modulators, pressure sensors, gas sensors, magnetic field sensors, laser damage sensors, sensor networks, and "smart structures". Dr. Lieberman also oversees research on fiber optic position encoders, voltage sensors, and infrared concentrators, biosensors, and moisture sensors. Over 35 publications bear his name, and he holds 4 U.S. patents. He founded and chairs the annual SPIE Conference on Chemical, Biochemical, and Environmental Sensors, and serves on numerous international conference committees and standards committees on chemical and physical fiber optic sensors.

Zongjian Sun, Research Scientist, will be responsible for the optoelectronics design during the project. He received his M.S. in Physics from Tongji University, China where he taught a course on fiber optics for four years. Since 1982, he has conducted research on fiber optics and fiber sensors. In 1984, he was the first scientist to successfully measure fiber scalar mode propagation constants. In 1989, he developed the world's smallest prism at the U.S. National Bureau of Standards. Currently, he is working on multi-mode wavelength division multiplexing, integrated optic and fiber optic networking devices, and optoelectronics modules for use in a fiber optic sensor reporting network.

8.0 CONSULTANTS AND SUBCONTRACTS

No consultants or subcontracts will be involved in the execution of this Phase I project.

9.0 EQUIPMENT, INSTRUMENTATION, COMPUTERS AND FACILITIES

Located in Torrance, California, 10 miles south of Los Angeles International Airport, POC's facilities occupy a total of 32,000 square feet in two separate buildings. Both buildings contain laboratories and equipment that contribute to POC's ability to develop, fabricate, and test devices for this program. The Company's major laboratories are dedicated to photonic systems, holography, fiber optic data links, fiber optic sensors, spectroscopy, integrated optics, and neural networks. With over $3 million invested in capital equipment and facilities, POC is confident that it will be able to provide the required level of performance.

The laboratories of the **Research and Development Division**, where the proposed project will be housed, occupy 14,000 square feet. POC's R&D facility is designed to serve applications in various areas of photonics including optical interconnects, optical computing, neural nets, information processing and fiber optic device fabrication and testing. Our Photonic laboratories are supplied with a full set of equipment necessary for fabrication and testing of various types of optical interconnects, including chip-to-chip interconnects, back plane interconnects, and reconfigurable interconnects using free space as well as waveguide implanted interconnects. Our Advanced Fiber Optic laboratories are equipped with a full supply of optoelectronic sources and

detectors, positioning equipment, spectral analysis facilities, and chemical and physical sensor test facilities. Overall, the R&D Division has accumulated capital equipment valued at $1 million.

The **Applied Technology Division** facilities are dedicated to the development and fabrication of optoelectronic prototypes and hardware for communication applications. The AT division is fully equipped for fabrication and characterization of data communication devices such as fiber optic links and wavelength division multiplexers. The AT laboratories also have equipment for fabricating a variety of integrated optic devices such as channel waveguides, polymer waveguides and holographic splitters for interconnections. In addition, our AT division facility has electronic assembly and machining capabilities with capital equipment valued at about $700k.

POC's **Product & Engineering** facility occupies 10,000 square feet. This division is equipped for the fabrication and testing of optical systems and components, including optical coatings and holographic products from the UV to IR range. The P&E laboratories and production area have full environmental stabilization with humidity and particle count control. In addition, P&E's spectrometry lab has two spectrometers (ISA and Perkin-Elmer), for spectral analyses from UV to IR. Total capital equipment and clean rooms in the Product and Engineering Division exceed $1.3 million in value.

10.0 CURRENT AND PENDING SUPPORT OF PRINCIPAL INVESTIGATOR AND SENIOR PERSONNEL

The time commitments (in person-months) listed below represent the work commitments of the key personnel for the time from January through June 1994.

Ed Mendoza:
Dr. Mendoza has no current or pending support for the NSF grant period 1/94 to 6/94, nor does he have proposals, other than this one, under consideration for performance during that time period.

Robert Lieberman:

1. **Current Support:**
   a. "A Highly Survivable Rapid Deployment Hybrid Remote Sensor Reporting System," Air Force SBIR, R. Lieberman, P.I., period of performance 9/29/92 to 7/29/94, $397,856, 1.0 month.
   b. "Damage and Power Sensors for High Power Laser Delivery Fibers Using Low-Cost Fluorescent Optical Fibers," DOE SBIR, R. Lieberman, P.I., period of performance 5/25/94 to 5/24/96, $490,000, 1.0 month.

2. **Pending Support:** None within the NSF grant period.

3. **Support Under Consideration and/or to be Submitted in the Near Future:**
   a. "Ring-Laser Mass-Flow Sensor," NSF SBIR, R. Lieberman, P.I., period of performance 1/94 to 6/94, $64,961, 1.0 month.
   b. "Submicron Fiber Optic Chemical Sensors with Millisecond Response Times," NSF SBIR, R. Lieberman, P.I., period of performance 1/94 to 6/94, $64,982, 1.0 month.

Zongjian Sun:
Mr. Sun has no current or pending support for the NSF grant period 1/94 to 6/94, nor does he have proposals, other than this one, under consideration for performance during that time period.

11.0 EQUIVALENT PROPOSALS TO OTHER FEDERAL AGENCIES

There is no prior, current or pending support for a similar proposal.

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